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DESCRIPTION OF THE DATA ACQUISITION AND INSTRUMENTATION SYSTEMS: JERSEY CITY TOTAL ENERGY PROJECT

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

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MODULAR INTEGRATED UTILITY SYSTEMS

improving community utility services by supplying electricity, heating, cooling, and water/ processing liquid and solid wastes/ conserving energy and natural resources/ minimizing environmental impact

Prepared for:
Department of Housing and Urban Development
Energy, Building Technology and Standards Division
Office of Policy Development and Research
Washington, D.C. 20410

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DESCRIPTION OF THE DATA ACQUISITION AND INSTRUMENTATION SYSTEMS: JERSEY CITY TOTAL ENERGY PROJECT

by

Charles Bulik, William G. Rippey, C. Warren Hurley, Dan E. Rorrer

ABSTRACT

Under the sponsorship of the Department of Housing and Urban Development (HUD), the National Bureau of Standards (NBS) gathered engineering data on an operating diesel total energy plant which supplies all electrical power, hot water, and chilled water to a 485 unit apartment/commercial building complex in Jersey City, New Jersey. Engineering data was continuously collected from April 1975 to December 1978 by a data acquisition system (DAS) which recorded the outputs from approximately 200 sensors located in the plant and site buildings.

This report describes the design and operation of the instrumentation system and the data acquisition system used to monitor the total energy plant and certain utility services to the site buildings. The report contains a description of the types, characteristics and locations of instruments used to measure physical variables. The capabilities and operational modes of the data acquisition system are discussed and the major data acquisition system components are described in detail. The report also contains a brief description of the total energy plant and site, instrument costs, data processing procedures and some of the instrumentation problems encountered.

Keywords: Data acquisition system; Digital tape recorder; Fuel measurement; Instrumentation; Total energy; Transducers; Weather station

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1. INTRODUCTION

The instrumentation and data acquisition system described in this report was used to collect data on energy use and total energy plant operation on an apartment building complex (Summit Plaza) in Jersey City, New Jersey. The total energy plant produced all electricity, space heating, domestic hot water heating and chilled water for air conditioning services used on the site. The development and construction of the Jersey City site was directed by the Department of Housing and Urban Development (HUD) under its Operation Breakthrough program. The Operation Breakthrough program initiated innovative housing projects throughout the United States. The total energy plant was developed, contracted and operated by HUD, under its utilities program.

Under contract to HUD, the National Bureau of Standards designed and installed a data acquisition system (DAS) and the instrumentation to gather data for an evaluation of the economy, efficiency and reliability of the total energy system.

1.1 SITE DESCRIPTION

The Jersey City site included a total energy plant serving the residential complex of 485 dwelling units in four medium to highrise apartment buildings, an elementary school (kindergarten through grade 3), a business building (with 46,000 square feet of commercial space) and a swimming pool. A central equipment building (CEB) housed the total energy plant and the collecting apparatus for a site pneumatic trash collection system.

Figure 1 is an aerial photo of the site and surrounding area. Figure 2 is a plan view drawing which identifies the site buildings. The first apartment tenant moved into the site in March 1974, and apartment occupancy was at 96 percent by October 1974. The first commercial tenant moved into a storefront on Kennedy Boulevard in October 1975, and the first school session began in September 1976.

1.2 TOTAL ENERGY PLANT DESCRIPTION

The total energy plant, figure 3, consisted of five 600 kW diesel engine-generators, figure 4, two 13.4 MBtu/hr (4.0 MW) hot water boilers and two 546 ton (1.9 MW) absorption chillers. The engine-generators and boilers used #2 fuel oil from three 25,000 gallon (95,000 ℓ) underground storage tanks. A pneumatic trash collection system moved trash from apartment building deposit chutes through an underground pipe to the central equipment building where the trash was compacted and removed from the site by trash disposal trucks.

In conventional electrical power generation stations, engine-jacket heat and exhaust gas heat are expelled into the atmosphere as waste. At the Jersey City site, a closed primary hot water (PHW) loop recovered heat from the engine-jacket and exhaust heat exchangers to supply the space heating, cooling and domestic hot water heating needs of the site. When the plant or site thermal energy demands exceeded that produced by the plant engine heat recovery, auxiliary boiler(s) were put into service. Figure 5 shows the primary hot water loop circulation through the engines, boilers, chillers, heat exchangers, dry coolers and emergency heat exchanger. Two pumps circulated the 180° to 230°F (82° to 110°C) primary water at a rate of 11,000 lbs/min (500 kg/min).

Heat recovered by the primary hot water loop was used to meet the thermal energy needs of the site. The site heat exchanges in the plant transferred heat from the primary hot water loop to two secondary hot water loops. Secondary hot water was circulated to site buildings to provide space heating in the winter and to heat domestic hot water year round. During the summer, PHW circulated through one or both of two absorption water chillers producing 45°F (9°C) chilled water for CEB and site air conditioning needs. A four-pipe system circulated hot and chilled water to site buildings through underground insulated piping. When thermal energy demands for the site and chillers were very low, a forced convection dry surface heat exchanger (dry cooler) released excess PHW heat to the atmosphere to control the PHW temperature and prevent overheating of the engines. An emergency heat exchanger using city water backed up the dry cooler.

Electrical power generated by the total energy (TE) plant was distributed to the site through two separate feeders to each building; an essential power feeder and a normal power feeder. In the event of a complete TE plant electrical outage, the essential feeder only was automatically switched to the local utility power bus to maintain operation of site emergency lighting, fire protection systems, elevators and plant engine

startup and support equipment. Figure 6 shows the power feeder arrangements in the CEB.

1.3 NBS INSTRUMENTATION AND DATA ACQUISITION SYSTEM

The Jersey City site was instrumented with 223 transducers measuring and converting physical variables into electrical signals that were recorded on magnetic tape by the Data Acquisition System (DAS). The DAS recorded data every five minutes, 24 hours a day and completed a scan of all 223 instruments in 30 seconds. A data tape reel was removed from the site periodically, about every week and returned to the NBS where it was processed on a mini-computer to produce information on site operation, efficiency and reliability. The rationale for a five minute sampling interval and a 30 second scanning speed is presented in Sections 4 and 5.3, respectively. Section 2 discusses measurement objectives. Section 3 describes, in detail, the instruments used at the site. Sections 4, 5, and 6 describe the DAS capabilities and operation. Section 7 describes data handling and Section 8 and 9 indicate instrument costs, selection and accuracies.

2. MEASUREMENT OBJECTIVES AND MAJOR SITE COMPONENTS

When the Jersey City Breakthrough site was selected by HUD to be the demonstration Total Energy site the NBS prepared an evaluation plan and conducted a study of the site architectural plans, power plant design and site plumbing and electrical distribution plans to determine the number and types of instruments that would be required to obtain the measurements necessary to perform the site evaluation. The following three areas were addressed: overall site energy use, the energy efficiencies of the plant and its components, and the reliability, quality and economics of the utilities supplied by the plant. From this study of site layout and methods of distribution of heat, water, cooling and electrical power the 200 plus measurements necessary to provide sufficient data for an evaluation of the total energy site were identified.

Fuel oil, stored in underground tanks, was the single energy source for the Jersey City site. An evaluation of operating efficiency and reliability calls for the measurement of: fuel consumption by the plant engine-generators and boilers, hot water and chilled water flow rates, gross generated electrical power, heat and power consumption by the dwelling complexes and by the plant support equipment. A record of site weather conditions, temperature, humidity and solar radiation, provided a means for correlation between site energy demand and weather conditions. The following sections, 2.1 through 2.7 identify the major site components and the parameters that were measured.

2.1 ENGINE-GENERATOR MEASUREMENTS

The engine-generator units were instrumented to determine the fuel consumed and rate of fuel consumption, electrical power generated, heat transferred to the water jacket and heat lost in the exhaust gases.

From these measurements the efficiency of the engines and amount of heat recovery could be determined.

Each engine generator unit consisted of a 600 kW generator driven by a water-cooled, V-12 turbocharged/after-cooled diesel engine fueled with number 2 fuel oil. The generators supplied three-phase, 60 hertz electrical power through a 4-wire "Y" system at a line voltage of 480 volts (figure 6). Thermal energy was recovered from the engine jackets and exhausts.

The five engine-generators fed a main power bus. The main bus was instrumented to measure the total electrical power (gross power), line voltage, frequency, and power factor. Measurements were also made of the total fuel consumed by the bank of five engines, primary hot water flow, primary hot water temperature rise across the engine bank and the water temperature at the engine inlet. The DAS was designed to receive malfunction signals from each engine-generator unit. Figure 7 illustrates the engine-generator instrumentation system. Since all five engine-generators were the same model and tests conducted at the Caterpillar factory prior to installation indicated nearly identical performance, only units one and two were equipped with additional instruments to measure electrical power output, jacket water temperature, exhaust heat exchanger temperature, lubrication oil/after-cooler temperature, exhaust gas temperature, engine running time, lubrication oil temperature and oil pressure (see figure 8).

2.2 PRIMARY HOT WATER LOOP MEASUREMENTS

The thermal energy flowing into and out of the primary hot water loop was determined by measuring the water flow rate in the loop and the differential temperatures across the engines, boilers, heat exchangers and chillers. Figure 9 shows the major heat exchange units within the primary hot water loop and the measurement points.

2.3 BOILER MEASUREMENTS

Hot-water boilers, burning #2 fuel, supplied thermal energy to the primary hot water loop (PHW) whenever the PHW temperature dropped to 180°F. The energy into the boiler was determined by measuring the fuel consumed by the boilers and having the computer calculate the energy from the Btu's per gallon and the measured gallons. The actual thermal energy transferred to the PHW loop was determined by measuring the differential temperature across the boilers and the primary hot water flow rate. Exhaust stack gas temperatures were measured to determine energy losses through the stacks. Figure 10 shows the primary water flow through the boiler units and the measurement points.

2.4 CHILLER MEASUREMENTS

The two absorption chillers used primary hot water to generate chilled water at 45°F (7°C) for air conditioning of the plant and site buildings. The system was usually in operation from May through October. To

calculate the performance of the absorption chiller system, the measurement system provided data to determine the energy input from the PHW system, the energy output to the chilled water system, and the energy rejected through the cooling tower system. Referring to figure 11, a flow diagram of the chilled water system, the thermal energy input was obtained by measuring the PHW flow and the differential temperature at the inlet. Thermal energy output was calculated from the chilled water flow rate and the inlet-outlet temperature difference. The cooling tower thermal energy losses were, similarly, a product of the water flow rate and differential temperature. The chiller measurement points were specifically chosen to permit a calculation of coefficient of performance of the system and each chiller. The amount of thermal energy (as chilled water) being delivered to the East zone and West zone buildings was also measured as indicated in figure 11. The East zone contained the Pool, School, Shelley A and Shelley B buidlings. The West zone included Camci, Descon and Business buildings (see figure 2 for a plan view of the site).

2.5 SECONDARY HOT WATER

The secondary hot water loop receives heat from the primary hot water loop through two heat exchangers that are located in the CEB. The SHW circulates from the CEB to the site buildings. The thermal energy supplied to the heat exchangers by the PHW loop was determined from the flow rate and differential temperature measurements indicated in figure 12. The thermal energy delivered to the site buildings was determined from flow and temperature measurements made in the secondary hot water loop (figure 12).

2.6 ELECTRICAL SYSTEM MEASUREMENTS

Three phase, 60 hertz electrical power was distributed at a line voltage of 480 volts to the site buildings and to pumps and motors within the power plant.

Figure 13 shows a schematic of the electrical distribution system and the measurement points. The generator main bus branched into two feeder busses, a normal and an essential bus. The normal feeder provided electrical power for electric cooking ranges, ventilation, apartment and office lighting and applicances in the site buildings. The chillers, exhaust fans, and hot water pumps not directly involved in the PHW loop operation (through motor control centers MCC-2 and MCC-3) and the central pneumatic trash collection system (PTC) are also on the normal bus. The essential load bus provided electrical power to the plant through MCC-1 (see Figure 14) and to branches that service plant lighting, site emergency lighting, site fire protection, site elevators, boilers, dry coolers, pumps directly related to the PHW loop, electrical control equipment, and the NBS instrumentation system. In the event of electrical plant outage, essential loads were automatically switched to the local electric utility (Public Service Electric and Gas) power bus.

Engine-generator units 1 and 2 were each instrumented to measure generated electrical power. The main power bus was instrumented to measure total generated electrical power, power factor, frequency, and line voltage. Power consumption measurements were made on the following branches: plant lighting, three motor control centers (MCC1, MCC2, MCC3), PTC exhauster, normal power bus at each building, essential power bus at each building. Power bus line voltages were monitored at each site building and at the local utility's input feeder. The PTC system contained two exhausters driven by 150 HP motors, a hydraulic trash compactor and a series of control valves. A continuously operating exhaust fan prevented unpleasant odors from acculmulating in the system. The large exhausters, which represent over 90% of the PTC load, were instrumented for electrical power consumption.

2.7 SITE BUILDING MEASUREMENTS

The buildings on the site received all electrical, cooling and heating services from the central total energy plant. These buildings consisted of four apartment buildings, a commercial building, an elementary school and a swimming pool.

Measurements were made in each building to determine thermal energy used from the secondary hot water loop for space heating, thermal energy used to produce domestic hot water, thermal energy added to the secondary chilled water system, electrical power consumed on normal and essential electrical busses, and normal line voltage. Figure 15 shows the measurements made in a typical building.

Some buildings deviated slightly from this plan, for example, the pool was not air conditioned and therefore did not use chilled water. From measurements made at each building a determination could be made of building energy demands and of the losses in the secondary distribution systems.

Schematic diagrams of transducer locations and their respective NBS code numbers for the site hot water and chilled water distribution systems are included in appendices 1 and 2.

3. INSTRUMENTS USED AT THE TOTAL ENERGY SITE

The instruments installed at the total energy site measured the following parameters: electrical power, voltage, water and fuel oil flow rates, actual and differential temperatures, exhaust gas pressure, lubrication oil pressure, water pressure, engine-generator malfunctions, barometric pressure, solar radiation, wind velocity and wind direction. The transducers and their associated signal conditioning circuits are described in this section.

3.1 ELECTRICAL INSTRUMENTATION

Twenty-three electrical power and eleven voltage measurements were made at the site. Of these thirty-four measurements, thirteen were in the

power plant and twenty-one were in remote buildings. Additional instruments installed in the engine control room in the CEB and independent of the DAS included a kilowatt-hour meter registering the total produced power and strip charts recording frequency, power and line voltage levels.

3.1.1 Voltage

Power bus voltage levels were measured by converting the AC line voltage to a DC level. The 480 VAC line voltage was stepped down by a 4:1 potential transformer to 120 VAC. (The 120 VAC range was compatible with circuit component ratings and a safety factor was gained by being isolated from the 480 volt line through the potential transformer). A full-wave rectifier circuit and R-C filtering converted the 120 VAC signal to a DC analog level which was recorded by the DAS.

3.1.2 Electrical Power

Electrical power measurements were performed by Hall-effect watt-transducers. These devices were connected to electrical busses thru potential and current transformers which provided input signal levels compatible with the semiconductor transducers.

The Hall-effect transducer multiplied the instantaneous voltage and instantaneous current signals from the potential and current transformers performing the computation $V \cdot I \cdot \cos \phi = P$ (watts). The transducer analog DC output was electronically integrated to produce integrated power (kilowatt-hour) data. Integration of the transducer output from kilowatts to kilowatt-hours was accomplished by a pulse-counting scheme as shown in Figure 16. A voltage-to-frequency (V-F) converter generated pulses at a rate proportional to the Hall transducer output voltage. These pulses were summarized by a 12 stage digital counter. The binary output of the counter was fed to an 8 bit digital-to-analog converter (DAC) whose output varied from 0 to +5.00 volts DC. This output voltage was sampled and recorded by the DAS. The maximum output voltage of +5.00 volts DC corresponded to 8192 counts. The next pulse (above 8192) reset the output voltage to zero.

In order to maintain the total pulse count between data scans to less than 8192, a dividing (scaling) circuit was inserted at the input to the counter which divided the input pulses by powers of two (2^N). N could be set to any value from 0 to 9 by a thumbwheel switch mounted on the integration printed circuit card.

A line diagram of a typical power bus instrumented for voltage and kilowatt hour measurements is shown in Figure 17.

The power measurement system and integrating circuits were designed and built at the NBS.

3.2 FLUID FLOW INSTRUMENTATION

Water flow measurements for primary hot water, chilled water, secondary hot and chilled water and cooling tower water were obtained through venturi tubes, differential pressure transducers and nutating disk meters. Two totalizing nutating disk flow meters registered the fuel consumed by the engines and by the entire plant and provided back-up data if the turbines or DAS malfunctioned. Differential pressures from thirty-one venturi tubes, two nutating disk flow meters and seven turbines were monitored by the DAS.

High water flow rates were measured by venturi tubes with differential pressure cells. Low flow rates were measured by nutating disk flowmeters. The thirty one venturi tubes were installed in water pipes which varied from one to ten inches in diameter, and sensed flow rates from 300 to 20,000 pounds per minute. Nutating disk flowmeters measured secondary hot-water flow in the school and commercial building.

The flow rate through a venturi is measured by sensing the pressure drop in the venturi's throat due to the increased velocity of the flow in the throat. The pressure drop is given by:

$$\Delta P = \frac{V^2 P}{2g} \left[1 - \left(\frac{A_2}{A_1} \right)^2 \right]$$

where V is the flow velocity in the throat, p is the fluid density, g is the gravitation constant, and A_2/A_1 is the ratio of the pipe area to the throat area. A differential pressure cell measures this pressure drop. A typical piping arrangement and installation of a venturi and differential pressure cell are shown in Figures 18 and 19. The pressure cell is mounted below the venturi to prevent static errors occurring from air collecting in the lines. A typical venturi is shown in Figure 20; the wire handles are connected to cleanout rods used to clear the venturi's pressure pick-off anulus.

The differential pressure cell is a solid-state device consisting of a bellows that displaces a strain gauge connected to a bridge and amplifier circuit. The device generates a 4 to 20 milliampere signal current which corresponds to the minimum and maximum differential pressures, respectively. The signal current flows through a precision 500 ohm resistor and produces a signal voltage that varies from +2.0 to +10.0 volts DC. This voltage level is directly proportional to differential pressure in inches of water. The differential pressure transducers used at the site had a range from 0 to 150 inches of water.

The venturis were selected to produce a differential pressure of approximately 150 inches of water at the maximum anticipated flow rates. Each venturi was delivered with an individual calibration chart and these data are incorporated in the computer's data processing routines. Typical venturi are included in appendix 4.

The differential pressure cells were periodically recalibrated at the site. The venturi clean-out rods were periodically plunged to prevent sediment from plugging the venturi's pressure ports (see Figure 21). To minimize the possibility of fouling of the pressure cells, the cell lines were periodically opened to drain any collected sediment.

The nutating disk flowmeters were equipped with a reed relay that provides contact closures, as the fluid flows through the meter. The contact closures, which correspond to unit volume of flow, were sensed by an electronic circuit that generates a pulse for each closure. The pulses were totalized by a digital to analog converter into an analog voltage which was sampled by the DAS. A nutating disk meter is relatively immune to fouling.

3.2.2 Fuel Flow

Seven turbine meters were used to measure individual fuel consumption of the five engines and two boilers. These turbines (see Figure 22) were capable of accurate measurement for flow rates as low as 0.1 gallons per minute. Figure 23 shows the locations of the fuel measuring instruments.

The turbines were installed upstream of the injector racks on the engines and upstream of the firing nozzles on the boilers, (see Figure 24 and 25). A three valve arrangement for each engine turbine allowed fuel to be by-passed around the turbine permitting removal of the turbine without disturbing the operation of the engine. No bypass was provided on the boiler turbines since depressurization of the fuel line and replacement of the turbine required a simple boiler shut down of less than five minutes duration.

The turbine output was a 10 to 100 millivolt peak-to-peak sinusoidal signal developed by a magnetic pickoff. As shown in Figure 26, this signal was amplified, shaped, divided (if necessary) and counted (totalized) in a 10 stage counter. The binary coded decimal output of the counter fed the digital-to-analog converter. The analog DC voltage output of the DAC was sampled and recorded by the DAS.

Each turbine was delivered with 10 point calibration tables for test runs conducted with #2 fuel oil at 68°F and 86°F. The calibrations were checked and confirmed at NBS. The individual turbine calibration data were incorporated in the NBS computer software which processed the data received from the site.

3.3 Temperature Instrumentation

There were 54 thermocouples measuring actual temperatures and 42 thermopiles measuring differential temperatures on the Jersey City total energy system. All but five of the temperature measurements were made by Type T, copper-constantan, thermocouples and thermopiles. Type J, iron-constantan, thermocouples were used to measure engine exhaust stack and boiler exhaust stack temperatures.

For water temperature measurements, the thermocouples were potted and mounted in stainless steel wells as shown in Figures 27 and 28.

Differential temperatures were sensed by multiple pairs of copper-constantan thermocouples combined into thermopiles. The higher signal level generated by the thermopile provided greater temperature resolution by the data acquisition system (DAS).

Each thermopile had one thermocouple junction which was used with an ice-point reference junction to measure the actual thermopile temperature which is needed to compute the differential temperature from the thermopile voltage. The thermocouples, thermopiles and thermowells were fabricated and calibrated by NBS in accordance with ASTM practices.

Thermocouples require reference temperature junctions to measure actual temperatures. The CEB and each building on the site was equipped with an ice-point temperature reference unit. These units thermoelectrically cool very pure water to the point that ice begins to form, producing the desired reference temperature.

3.4 ALARM SENSORS AND INSTRUMENTATION

Because the reliability of the engine-generators was of particular importance in the analysis of the Jersey City Total Energy system, the ability to identify and record specific malfunctions that caused an engine-generator to shut down or flash alarm signals was incorporated into the instrumentation.

Twelve functions were monitored by the plant control system for each engine-generator to indicate whether electrical, mechanical and thermal systems were within normal limits, a total of 60 malfunction signals for all five engine generations. Each monitor has only two output levels, a low level when conditions were normal and a high level when conditions were out of limits. To reduce the number of DAS channels from 60 to 10 channels, a digital weighting scheme was designed (see Figure 29). Groups of six alarm signal lines were connected to a digital-to-analog converter (DAC). Each discrete output level from the digital-to-analog converter represented a unique combination of <u>on</u> and <u>off</u> states of the six inputs.

The following alarms and malfunctions were instrumented on each engine-generator.

Engine	Generator
low oil pressure	circuit breaker trip
high oil temperature	
high oil coolant temperature	overload
high jacket water temperature	failure to parallel
overspeed	
underspeed	reverse power protection
excessive start time	
excessive vibration	

Difficulty was encountered in recording the malfunction signals because of peculiarities in the engine control system wiring. These problems are discussed in Section 10.5.

3.5 WEATHER INSTRUMENTATION

Seven weather measurements were made at the site: air temperature, humidity, barometric pressure, wind direction, wind speed, direct solar insolation, and indirect solar insolation. Two of these measurements (dry bulb temperature, humidity) are made in an instrument shelter box located on the roof of the Descon building (see Figure 30). A small exhaust fan continuously circulates outside air through the box. Air temperature is measured by a thermistor and bridge circuit and a hygroscopic hair-type element coupled to a potentiometer measured relative humidity. Two pyranometers were located on the roof of the elevator shaft penthouse (Descon building) and measure direct solar insolation and indirect insolation. These instruments are constructed with thermopiles that are placed under black and white areas of an exposed disc. The signal from the thermopile is directly proportional to the radiant energy striking the disk. The direct (Figure 31) and diffuse units differ in that the diffuse unit was shaded from the direct radiation from the sun by a shadow band (see Figure 32). The shadow band was adjusted each week to compensate for the seasonally changing declination angle of the sun.

An aerovane measured wind velocity and wind direction. The instrument was mounted, on a thirty foot tower on the roof of the Camci building. (See figures 33 and 34). Camci was chosen for the aerovane location because it is the tallest building on the site and is equipped with a lightning protection grid. Signals from the aerovane are sent to the central DAS through Camci's remote DAS station.

4. DATA ACQUISITION SYSTEM

4.1 SITE REQUIREMENTS

The features of the DAS were designed to provide the data needs for a TE system performance analysis as discussed in section 2.0 and to be adaptable to the physical site configurations. The number of measurements required for the performance analysis was over 200. Due to the site layout, measurements had to be made at widely separated points over a

6.3 acre area with instruments located from 15 feet below ground level to heights of 17 stories. Data recording had to be in a format suitable to rapid reduction and system operation had to require a minimum of operator attendance.

A digital computer performed the data reduction and analysis tasks to accomplish timely processing of site data. Since all sensors at the site were analog devices, the question arose as to where to make the signal conversion into digital form. The digital conversion could be accomplished anywhere in the signal transmission chain, from transducer to tape recorder. If the conversion was made at the transducer, the sensor was considered to be a digital device and interconnecting cables had to be capable of carrying digital information. If a digital sensor signal is transmitted over a single signal pair of wires then the digital data has to flow in a serial fashion and the time required to sample 200 points could be several minutes. If the sensor data are transmitted in parallel form, the sampling speed increases significantly, however the requirement for additional signal lines increases by a factor of six because each sensor requires at least six signal lines (to transmit a 5.00 volt signal in binary code with an accuracy of 1.6% requires six lines). Six lines will resolve the signal into 63 parts, therefore the smallest signal increment is: 5.00 volts/63 = .079 volts or 1.58% of the maximum value). If the analog to digital conversion was made at a point where the signal transmission path became common to all sensor signals then an optimum balance could be achieved between data sampling speed, minimum signal cable requirements and less complex wire routing. The decision was made in favor of locating an optimum point where the digital conversion could take place. This optimum point was the common signal path at the input to the scanner controller. The scanner controller directed all the analog signals to the DVM where they were digitized. The signal flow diagram in section 4.2 shows the convergence of sensor signals to the scannner controller unit.

4.2 DAS DESCRIPTION AND DATA SAMPLING RATIONALE

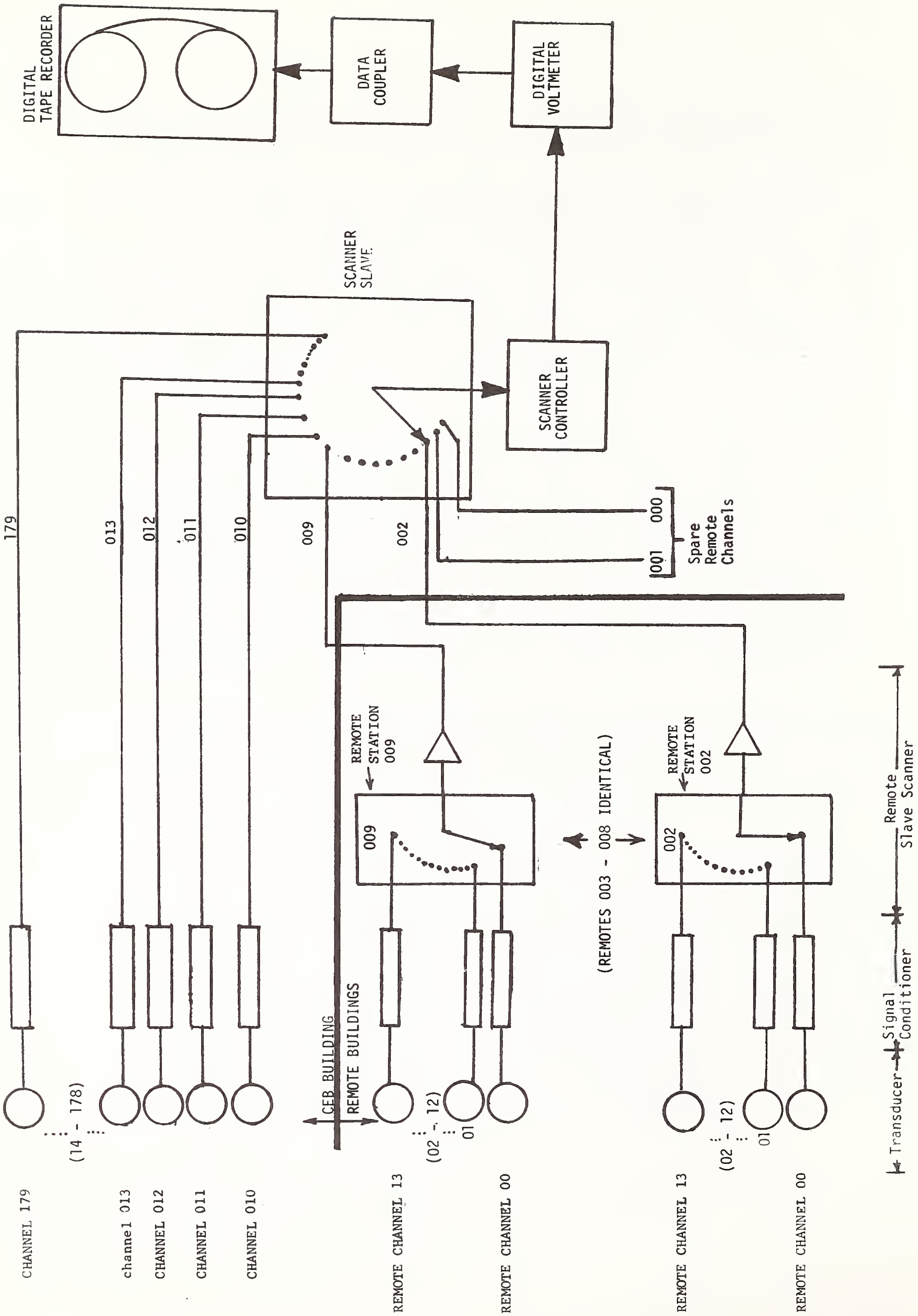
The function of the data acquisition system was to sample 223 analog signals generated throughout the total energy complex, digitize the analog signals and record them in digital code on magnetic tape. A data scan was initiated every five minutes and required 30 seconds to sample and record all the signals generated at the site.

The factors that lead to a 30 second recording speed are discussed in section 5.3, "DAS Scanning Speed". The following factors established the five minute sampling interval. To determine the optimum time interval between data scans, a study was made of the variations in water flow rates and temperature in the primary hot water loop, electrical power demand and fuel consumption. Water flow rates varied less than 2% within any 60 minute interval. Water temperature changes were gradual in any 15 minute period. Fuel consumption rates did not exhibit any abrupt changes in any one hour period. Total electrical power demand increased during the morning hours (6 a.m. to 8 a.m.) and evening hours (4 p.m. to 7 p.m.). These load variations were gradual over any 30

minute period. Of the 23 electrical branch loads that were instrumented for power consumption data, the pneumatic trash collection (PTC) system was the only cyclic load that required an appreciable amount of electrical power for very short periods of time. The PTC required 125 kilowatts of power and operates for five minutes in each hour. Selecting a five minute DAS sampling rate would identify a PTC system malfunction to within 5 minutes and consequently other system malfunctions would be narrowed to a five minute interval. The feasibility of establishing a five minute scan interval was governed by the magnetic tape capacity and the data tape service schedule established at the site. A ten-inch reel carrying 2400 feet of magnetic tape could record 282 channels of data every 5 minutes for 19 days (see section 6.8). A nineteen day capacity was compatible with a data tape collection schedule which anticipated a change of tape reels every week.

The data acquisition system consisted of a central DAS located in the central equipment building (figures 35, 36, 37) and eight remote DAS stations (figures 38 and 39). A remote station was located in each of the seven site buildings, the eighth station was installed on the roof of the Descon building to service the weather station instruments. Each remote station could monitor data from fourteen sensors, for a total of 112 remote data channels. The central DAS was built by Monitor Labs of San Diego, California to specifications provided by NBS (see appendix 3). The signal processing and conditioning circuits used in the remote stations and in the central equipment building were designed and fabricated at the NBS.

Signals from the transducers located in the central equipment building (170 local data channels) were connected directly to the central DAS by shielded cables. Transducer signals generated at the weather station and at site buildings were sent to the remote stations where they were conditioned and then transmitted to the central station. To minimize the complexity of installing a separate pair of signal wires from each of the 112 remote points to the central DAS, a multiplexing scheme of data channel selection was used. One signal line was connected between the central station and each remote station. The central station selected a remote data channel, recorded the data on magnetic tape, then disconnected the channel and proceeded to select the next data channel. In this manner the fourteen signals at each remote station could be serviced, one at a time, over a common line. The DAS channel selection sequence started with the remote stations and recorded data from all the remote channels. Then the sequence moved to the CEB and the remainder of the data channels interrogated and their signal levels recorded on magnetic tape. The following figure is a simplified diagram indicating signal flow from transducer to tape recorder. The DAS scanned a total of 282 channels including 223 active data channels and 59 spare channels.


DIGITAL TAPE RECORDER
DATA COUPLER
DIGITAL VOLTMETER
SCANNER SLAVE
SCANNER CONTROLLER
179
013
012
011
010
009
002
000
001
Spare Remote Channels
CHANNEL 179
(14 - 178)
channel 013
CHANNEL 012
CHANNEL 011
CHANNEL 010
CEB BUILDING
REMOTE BUILDINGS
REMOTE STATION 009
009
REMOTE CHANNEL 13
(02 - 12)
01
REMOTE CHANNEL 00
(REMOTES 003 - 008 IDENTICAL)
REMOTE STATION 002
002
REMOTE CHANNEL 13
(02 - 12)
01
REMOTE CHANNEL 00
Transducer
Signal Conditioner
Remote Slave Scanner

4.3 DAS CAPABILITIES AND DATA HANDLING

The data acquisition system at Jersey City had the capability to monitor and record data from 170 channels in the central equipment building and 14 channels from each one of ten remote stations. In the final configuration the Jersey City site was using 8 remote stations with 2 stations available for future expansion. Each remote station is expandable to 30 channels and the central station is expandable to 1000 channels. Signals were transmitted, interference free, from remote stations to the central station for distances up to 700 feet (section 6.3 discusses signal transmission). The channel interrogation rate or scanning speed could be varied and was set at 9.4 channels per second. This scan rate was of sufficient speed, relative to the rate of change of the total energy parameters, to insure that each scan cycle is essentially an instantaneous moment for all the data channels. The 223 transducers installed throughout the plant and site buildings translated physical and electrical variables into analog voltage signals that were conditioned (i.e. amplified, scaled to uniform voltage levels, converted into pulses), digitized and recorded on the DAS magnetic tape recorder.

The parameters measured were:

Flow Rates

- Fuel oil flow rate
- Water flow rate

Temperatures

- Water
- Fuel oil
- Outside air

Electrical Characteristics

- Power
- Frequency
- Power Factor
- Voltage

Weather Characteristics

- Solar Radiation
- Humidity
- Wind Velocity
- Wind Direction

The only expedient approach to reducing the large quantities of raw data accumulated at the site was through computer data processing. The initial plan for this total energy site analysis provided for a digital computer to perform the system analysis. The data on the magnetic tape was

computer compatible and could be reduced and processed by standard software routines.

When the nine-track magnetic tape reel in the DAS had accumulated data for about a week, the reel was removed and sent to the NBS for data reduction on a Raytheon 704 digital computer. Data processing involved converting the signal voltage levels recorded on the magnetic tape into engineering units (kilowatts, gallons per minute, degrees Fahrenheit) and then transferring the enginering units, channel identification and the original voltage levels to a new seven track magnetic tape. The nine track DAS tape was placed in storage and the seven track tape supplied the data input to the computer for additional processing. The transfer of data from nine track tape to a digital computer was essentially an automatic operation after the operator has selected the proper software routine through the Cathode Ray Tube (CRT) keyboard and initiated a start command. There were provisions for operator and computer interaction during the data processing phase and these are discussed in section 7.2.

5. SYSTEM OPERATION

The data acquisition system operated in a full automatic, single scan mode initiated by a system start pulse generated by the DAS digital clock. Thirty seconds of data were recorded on magnetic tape at five-minute intervals. When the tape recorder was inactive, data could be transmitted over telephone lines to the NBS. The system was unattended requiring only occasional service and periodic change of magnetic tape reels. This period could be as long as nineteen days though NBS has found it expedient to remove and process a data tape each week. Section 5.8 discusses maximum recording capacity in full detail.

5.1 INPUTS

The central station digital voltmeter (DVM) would accept DC analog voltages ranging from $\pm$ 00.000 millivolts to $\pm$ 150.00 volts. Meter resolution was one microvolt on the millivolt range and one millivolt on the ten volt range. Input signals ranged from low millivolt to ten volt levels and were a function of the transducer and signal conditioning circuits. Thermocouples generated (on an average) a 15 millivolt signal, differential thermocouple signals were in the 10 to 24 millivolt range. Electrical power and turbine flow measurements were processed through digital to analog converters that produced a 0 to +10 volt signal. A differential pressure transmitter sensing venturi flow generated a +2.000 to +10.000 volt signal. Selection of the appropriate DVM range to suit the level of the incoming signal was an automatic feature of the DVM and is covered in greater detail in section 6.6.

5.2 OUTPUTS

Three data recording devices were serviced by the DAS, a magnetic tape recorder, a modem (modulator/demodulator) link and a printer. The DAS could send data to only one device at a time, therefore, if all three recording devices were selected (at the DAS coupler panel) to receive

data, the DAS would service the devices sequentially in the following order; tape recorder (one complete scan), modem (one complete scan), printer (one complete scan). Under normal operating procedures only the tape recorder and modem were selected. The printer was used when an operator desired printed data while performing a system calibration or output data check.

5.2.1 Magnetic Tape Recorder

The magnetic tape recorder was an incremental nine-track unit and was the primary data logging device. System timing pulses, scanning speeds and data update intervals were selected to utilize the high recording speed capability of the tape recorder. At the beginning of each five-minute interval the signal level from each transducer was recorded on magnetic tape. This was a 30 second operation (9.4 channels per second) and for the remaining four and a half minutes channel data were transmitted at a slower speed (approximately 168 seconds per scan) over the modem link.

5.2.2 Modem

When the tape recorder was inactive, the modem link was energized and DAS data transmitted over telephone lines to a Raytheon model 704 mini-computer at the NBS in Gaithersburg, Maryland. Transmitting one full scan of data took 2.8 minutes. The modem was a Vadic model VA300 with a maximum data tramsmission rate of 30 characters per second. The digital computer decoded the modem transmission, converted the data into engineering units and could display the characters on a cathode ray tube or store the data in computer memory for transfer to magnetic tape. The modem was a back-up for the tape recorder and provided an indication of site performance and a daily verification, at the National Bureau of Standards, that the DAS was functioning.

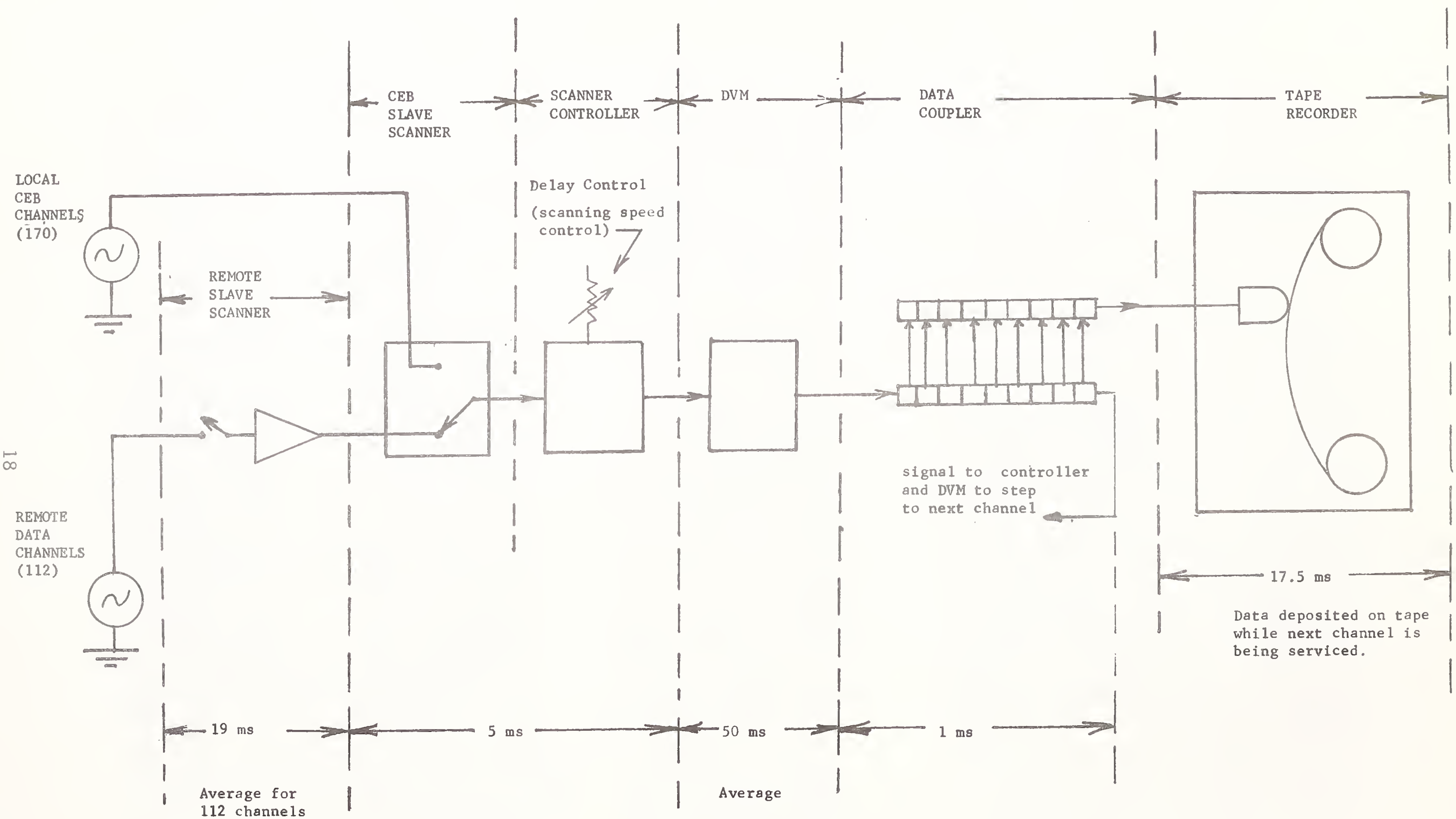
5.2.3 Printer

A Centronix model 301 impact printer was located at the site and provided a hard copy output of data channel information (figure 42). The hard copy printout could be examined at the site to determine whether all data channels are operating properly. The data coupler formatted the output information to put label and time information on a separate line and then group channels, five to a line. A typical printer scan time for the 282 channels was four minutes. A sample of printer hard copy output is shown in figure 43.

5.3 DAS SCANNING SPEED

As shown in the DAS signal timing chart below, a transducer analog signal was routed and processed through: the remote slave scanner, CEB slave scanner, scanner controller, digital voltmeter, data coupler and tape recorder. All of the devices had an effect on the system scanning speed and as the following analysis indicates, the digital voltmeter was the device that set a limit on the maximum scanning speed.

DAS SIGNAL TIMING CHART



Time to scan and record 112 remote channels.

(112) X (19 + 5 + 50 + 1) = 8.4 seconds

Time to scan and record 170 local channels.

(170) X (5 + 50 + 1) = 9.52 seconds

The remote scanner took five milliseconds to sequence through a remote channel and also introduced a 200 millisecond delay between each remote station. The CEB slave scanner and scanner controller required five milliseconds to sequence through a channel. The digital voltmeter required from 41 to 58 milliseconds to digitize an analog signal with the average conversion time being 50 milliseconds. The 50 millisecond average is covered in greater detail in section 6.6, (Digital Voltmeter). The data coupler's delay was only one millisecond due its data buffering feature which is explained in section 6.7 (Data Coupler). When the DVM transferred data to the coupler the data was placed into a storage buffer, then the coupler signalled the DVM and the scanner controller to read the next channel and proceed to output the data from the storage buffer to the tape recorder in 17.3 milliseconds. The tape recorder then waited from 38.3 milliseconds to 60.7 milliseconds for data to arrive from the next channel. The time required to transfer data from the coupler to the tape recorder was not assessed against scanning time because the data transfer occurred while the DAS was processing the next channel. Tape recorder characteristics and recording speed are covered in section 6.8.

Determining DAS Scanning Speed:

Time required to scan all the remote channels.

5 milliseconds per channel X 112 channels	= .516 s
200 millisecond delay X 8 stations	= 1.6 s
	2.116 s

Average time to scan through a remote data channel. $\frac{2.116\ \text{s}}{112\ \text{channels}}$ = 19 ms per channel

Time to sample and record one remote data channel:

19 ms + 5 ms + 50 ms + 1 ms = 75 ms

remote scan + CEB scan + DVM + coupler

Time to sample and record one local channel (CEB):

5 ms + 50 ms + 1 ms = 56 ms

CEB scan + DVM + coupler

Time for total scan.

112 remote channels X 75 ms	=	8.4 s
170 local channels X 56 ms	=	9.52 s
		17.92 s

Maximum DAS scanning speed

$$\frac{282 \text{ channels}}{17.92 \text{ s}} = 15.7 \text{ channels per second}$$

With the DAS scan time adjusted to 30 seconds, the scanning speed of 9.4 channels per second (282/30) was well within the systems speed limit. It was also apparent that the DVM was the slowest device in the signal procesing chain and had the greatest effect on the system scanning speed.

5.4 OPERATIONAL MODES

The data acquisition system could be operated in three modes: single scan, continuous scan and monitor mode. The operational mode was selected at the scanner controller panel, (figure 44), by pressing the appropriate push button switches.

5.4.1 Single Scan

Single scan caused a single interrogation of all system channels and would record the beginning time of scan and the data from each channel when output was to the printer and tape. Selecting the modem output automatically enabled the continuous mode feature where the DAS would, at the end of each scan, reset the first channel and restart a scan until a manual stop or reset button is pushed. A slight departure from this occurred when both tape and modem are enabled, which was the normal operating mode of the DAS. A start pulse would start a scan and data were output to tape only. At the completion of the tape scan the scanner reset and the DAS entered the continuous mode with modem output enabled. The DAS would then scan in continuous mode with modem only output until the controller received another start pulse. A start pulse would always reset and restart the scanner, enabling tape output for the first scan only, and then change to modem. This allowed single tape scans to be written at regular time intervals, with the modem available continuously the rest of the time. System start pulses could be initiated by a time pulse from the digital clock or manually by an operator pushing the controller start button.

5.4.2 Continuous Mode

Continuous mode will cause the DAS to scan from the first channel to the last channel selected at the scanner control panel, (figure 42), and will continue to be repeated until the cause of the continuous mode is removed or until operator intervention.

Continuous mode is enabled automatically when modem output is selected. The continuous mode with tape only output would be utilized in an instance where recorded data is desired at shorter time intervals than the normal automatic clock interval.

5.4.3 Monitor Mode

In this mode the system continuously monitored one selected channel and continuously updated the display of the digital voltmeter and the channel stored display in the system controller unit. This mode was not used for output purposes. When appropriate buttons were depressed on the system controller panel, the DVM would read the voltage value on the channel selected by the scanner controller first point thumbwheel setting. The DVM update frequency was operator controlled and adjustable from one to four times a second. Monitor mode was used for observing a particular channel over a brief period of time.

6. MAJOR SYSTEM COMPONENTS

A central station located in the CEB, eight remote stations located in seven site buildings and the remote signal cables comprised the data acquisition system. The central station contained seven separate chassis mounted in a single rack. They were: the system digital clock, digital voltmeter (DVM), scanner controller, system controller, data coupler, slave scanner and a 9 track digital tape recorder (Figures 35, 36, 37). A remote station consisted of a remote scanner slave chassis, signal processing circuitry and signal terminal strips (Figures 38, 39). The signal and control cables from the remote stations and signal cables from the CEB transducers terminated in wall mounted junction boxes in the DAS room. Multipair shielded cables connected the terminal boxes to the scanner slave chassis.

6.1 DIGITAL CLOCK

The system digital clock, incorporating an accurate crystal time base, generated the correct day of the year and time of day. A digital readout displayed the day and time in hours, minutes and seconds. Recordable digital output data was sent to the coupler unit to be output to the system recording devices with each data scan record. The clock also issued a system start pulse to the scanner controller unit at a time interval that was selected by front panel controls (Figure 45). The interval between start pulses could be adjusted from 1 second to 9 days and was set to 5 minutes for the total energy site. The system start pulse was generated continuously and would initiate data scans at 5 minute intervals until an operator turned the start pulse switch to the off position. The clock was equipped with a continuously on-charge NICAD battery circuit that supplied power to the chassis in case of power failure. The battery would run the clock circuits for three hours to insure that clock accuracy was maintained through a power interruption. Clock adjustments, to accomodate daylight saving time, was made manually during a data tape exchange. The time correction was entered into the computer for all subsequent data tapes.

6.2 SLAVE SCANNER

Analog signals from the total energy transducers entered the data acquisition system at the slave scanner through relay contacts. The CEB slave scanner contained seventeen multiplexing printed circuit (PC) cards and logic circuitry to operate the relays. Each PC card contained 10 relays, one for each individual data channel. Thirteen command lines, from the system controller, selectively energized the relays in the slave unit. The input signals were connected to the DVM through the relay contacts. All analog data signals at the site were carried through shielded signal wire pairs.

Although relays cannot achieve the multiplexing speeds possible with transistor switching, they were chosen over solid state switches because they have very low resistance through closed contacts and low thermal offsets. The relays used for multiplexing had thermal offsets of less than one microvolt at 68°F (20° C) and contact resistances of less than 0.05 ohms. These specifications could not be met by solid state switches. Low thermal offsets and low contact resistance were necessary to successfully switch low level thermocouple signals in the millivolt range (where 20 microvolts represents one degree F) without signal degradation. The relays had a maximum switching speed of 200 channels per second which imposed no limitations on the 9 channels per second operational requirement. Figure 46 is a schematic of a 10 relay printed circuit card.

6.3 REMOTE SLAVE SCANNER

A remote slave scanner was located at each remote station and contained: a power supply, a 10 channel relay multiplexing card, a four-channel multiplexing relay card, a scaling card to attenuate signals greater than 10 millivolts, and an operational-amplifier (op-amp) adjusted to a voltage gain of 1000. The plugin relay assembly was identical to the one described in the slave scanner section 6.2. All remote signals are amplified and then transmitted to the central station.

There were considerable advantages in using an op-amp when analog signals were transmitted over relatively long distances, up to 700 feet between the remote station and the central recording station. Non-amplified low level signals (in the microvolt and millivolt range) transmitted in noisy environments would have been subject to being obscured by noise induced in the signal lines (a low signal to noise ratio situation).

The noise interference problem was brought under control by transmitting all analog signals at high levels, 1 to 10 volts, taking advantage of the very low output impedance (0.1 ohm) of the op-amps and using shielded signal wires. The op-amp low output impedance was conducive to reducing signal line noise pickup.

Transducer signal levels at the remote stations ranged from 1 millivolt to 5 volts. Levels that were below 10 millivolts were connected directly to the op-amp input. Signal levels above 10 millivolts were connected to a scaling card (that contained resistor attenuating networks) and reduced

to levels not to exceed 10 millivolts. A record of the scaling factors for each attenuated signal was part of the mini-computer processing program.

6.4 SCANNER CONTROLLER

The scanner controller determined which channels were to be scanned by establishing the first and last channel to be scanned. The setting of thumbwheels labeled "first point" and "last point" controlled the channels that were to be interrogated (Figure 44). Upon receipt of a start pulse, from the front panel run switch or from the system clock, the scanner controller would select data channels in numerical sequence starting at the "first point" channel and ending at the "last point" channel. The current channel selected was displayed on a digital readout. The system scanning speed was selected by the delay control and was adjustable from fifteen channels per second to one channel per second.

Selecting a channel was the process of connecting an analog voltage from a transducer to the digital voltmeter input terminals through relay contacts. The relays were located in the slave scanner chassis and the scanner controller closed the relay for the channel being interrogated. CEB transducers were connected directly to slave scanner relays on channels 010 to 179 (local channels). Remote slave scanners which selected and transmitted remote analog signals were accessed by channels 000 through 009. When a remote channel was selected the scanner controller activated the system controller which then sequenced the fourteen remote sub-channels. This control is evident in the schematic showing the DAS control signals and data flow, figure 41.

The scanner controller could operate in a single, continuous or monitor mode by selecting the appropriate front panel controls. These operational modes were described in Section 5.4.

6.5 SYSTEM CONTROLLER

The system controller interfaced functions of the DAS components by coordinating the timing of system pulses, commands and by controlling the transfer of data from the DVM and clock to the data coupler. It also controlled remote station multiplexing. A normal scan started with a start pulse from the digital clock which was routed through the system controller to the scanner controller where the "first point" channel was loaded and to the data coupler where an "enable" command was generated and sent to the magnetic tape recorder. The controller issued a pulse to the digital voltmeter commanding it to read the voltage signal at its input terminals. The signal was then encoded into binary coded decimal (BCD) form and transferred to the data coupler. The system controller then incremented the channels in the scanner controller by issuing a channel "advance pulse". For remote multiplexing, subchannel "first point" and "last point" thumbwheels, located on the controller front panel, determined the subchannels to be scanned. The normal setting was first point 00, last point 13. Beyond channel 010 only the scanner controllers sequencing circuits were involved. The system controller also

provided a means of selecting and displaying, on a five character front panel display, the voltage signal level for any channel. The channel was selected by thumbwheel switches labeled "channel stored". The display labeled "stored reading", figure 37, was updated each time the selected channel was scanned.

6.6 DIGITAL VOLTMETER

The digital voltmeter (DVM) converted the analog signals at its input terminals into a binary coded decimal (BCD) output signal. The DVM was a DANA Labs model 4800 five digit instrument. BCD data output was delivered on 18 lines; four lines for each of the four least significant digits (weighted 1, 2, 4, 8) and two lines for the most significant digit (weighted 1, 2). The meter measurement capabilities included DC volts, ohms, AC volts and voltage ratios. When incorporated in the DAS the DVM was wired to function only in the DC volts mode. The DVM had five voltage ranges; 10 millivolts, 0.1 volts, 1 volt, 10 volts, 150 volts. An autoranging feature automatically selected the best voltage range for a given input signal. An analog signal was digitized in 41 milliseconds, with the autoranging feature the time could be as long as 58.4 milliseconds. The increased time was due to the voltage comparison being made between the input signal level and the five voltage ranges. Maximum conversion time occured when a signal in the 10 mV range was followed by a signal in the 100 volt range. The minimum 41 ms conversion time (read time) occurred when succeeding signals are in the same voltage range. In order to minimize the DVM conversion time, transducer signals were grouped into blocks of ten where signal levels were all in the same voltage range. This block grouping resulted in an average conversion time (for 232 channels) of 50 milliseconds.

6.7 DATA COUPLER

The data coupler transferred binary coded decimal (BCD) data from the DVM to a maximum of three recording devices (tape recorder, modem, printer). The DVM data was placed into a storage buffer within the coupler and then the system controller and DVM were signaled to advance and read the next channel. While the DVM was digitizing the signal level in the next channel, the stored data was transferred to the recording device. This technique of overlapping functions produced faster scanning speeds. In the process of data transfer, the data was arranged into word groups and encoded for the recording device used. When interfacing with the magnetic tape recorder the data were encoded into Extended Binary Coded Decimal Interface Code (EBCDIC) format and a character transferred to the tape recorder in parallel 8 bit words. Data to the modem link and printer were encoded in American Standard Code for Information Exchange (ASCII) format and transferred in a serial bit stream. Pushbutton controls on the front panel were used to select the desired recording devices. In addition to the data handling operation the coupler inserted time, data and label information to the recording devices at the beginning of each data scan. Label information consisted of a group of 12 numbers that were manually selected by thumbwheel switches located on the front panel. The thumbwheels were set by an operator each

time a new tape reel was loaded. The numbers were selected to indicate the date and time the new reel was mounted and served as an identification number for each tape reel.

The data coupler could operate in a standby, automatic or single mode by selecting the appropriate pushbuttons on the front panel (see figure 47 for front panel controls). In the standby mode the coupler would issue all interface control signals but would not record data. This allowed system checks without unwanted recordings. In the single mode the DAS performed one scan and recording when the manual start button is pressed. In the automatic mode, which is the position for recording site data, a DAS scan was initiated by an external start command from the digital clock and data was recorded for each scan.

6.8 DIGITAL TAPE RECORDER

The DAS digital magnetic tape recorder was a Kennedy model 1610 incremental nine track write-only unit with provisions to record longitudinal and vertical parity bits for detection of erroneously recorded data (figure 48). In incremental recording each data character was written upon command. The tape transport advanced one increment upon command from the data coupler then stopped and waited for the next step command. The size of the step depended on the packing density (recording density) specification for the tape unit; the model 1610 density is 800 bytes per inch (bpi), therefore each step took up 0.0012 inches of tape. The data was evenly spaced on the tape regardless of the frequency of the data source provided the maximum stepping rate, 750 bytes per second (bps), of the recorder was not exceeded. At the maximum recording rate a byte (which represents one complete character) was recorded in 1.33 milliseconds. Data for a single channel (containing 13 characters) was recorded in 17.33 milliseconds. Figure 49 illustrates the data output format to the tape recorder. Tape capacity was 2400 feet of 1/2 inch, 1.5 mil computer tape mounted on a 10 1/2 inch reel. The length of time that the DAS could operate unattended could be determined by calculating the amount of data that could be deposited on a reel of tape with a data scan occurring every 5 minutes. The following calculations indicate that a reel of tape could store 19 days of data.

Number of characters in one complete scan of 282 channels:

282 channels X 13 characters plus:		= 3666 characters
label and time recorded at the beginning of each scan.	= 12 + 7	= 19 characters
		= 3685 characters
$\frac{\text{3685 characters}}{\text{800 bytes per inch}}$ plus:		= 4.6 inches of tape

a 0.6 inch interrecord gap (IRG) added to the end of each scan.	= 0.6 inches of tape
	= 5.2 inches of tape

Tape length per day.

12 (scans per hour) X 24 (hours) X 5.2 (inches)	= 1498 inches per day

Full reel recording capacity:

$$\frac{\text{Full reel of tape}}{\text{Daily Usage}} = \frac{2400 \text{ X } 12 \text{ inches}}{1498 \text{ inches per day}} = 19.2 \text{ days}$$

7. DATA PROCESSING

7.1 OUTPUT FORMAT

The DAS data output format was identical for all 3 output devices, see section 49. The first characters output during a scan were the 12 data coupler thumbwheel digits, the label data. Seven digits of the clock time data containing day of year and hour and minute of the day were output next, followed by channel numbers and voltage magnitude going from the scanner first point (of the first channel) through to the last point (of the last channel). The data coupler caused the tape unit to write an interrecord gap after the last point data was written. For printer output the coupler sent a carriage return and blank characters to arrange the hard copy characters into an easily readable form.

Figure 49 shows a layout of the DAS output format. Each DVM reading was output in a 13 character group containing 3 digits of the scanner channel number, 2 digit subchannel or 2 blanks, a one digit DVM function code, a plus or a minus sign for voltage polarity, five digits of data, and a one digit DVM range-code. One data record on tape contained 3685 characters.

7.2 DATA EDITING AND CONVERSION

All computer processing of raw data was performed on a Raytheon 704 minicomputer. The computer had 32K of memory with seven- and nine-track tape drives, two disk drives, CRT terminal with a hard copy machine and a high speed paper tape punch and reader. All data processing programs were resident in the system library on disk and could be loaded and executed by operator commands to the system monitor.

The time base for processed data output was a one hour period. For each data channel twelve five minute scan values were combined to yield a single data point representing the hour. Further processing yielded daily and monthly values for each measured variable. In addition, so called "derived variables" were calculated. These quantities were gallons of fuel consumed, kilowatt hours of electrical energy produced and consumed, and the heat (in Btu) produced or used in the TE system. A Btu calculation involved multiplying a water flow value by a delta temperature value

for hourly data values. All one hour, daily and monthly values for data channel variables and derived variables were stored on a monthly disk. Data points on disk could be displayed in a table form or on a X-Y plot display on the CRT, and hard copy printed.

Data processing routines were set up to read a scan and convert voltage readings to engineering units, automatically proceeding from scan to scan. The computer software would automatically handle data tape errors such as illegal characters, spurious interrecord gaps (IRG's) written before the last point channel is reached, and parity errors without interrupting the data processing routines.

Once editing routines had checked the raw data in a single scan for correct format and characters, and any needed corrections had been made, calculations could be performed that converted the analog voltage readings back to physical quantities. The software used the channel number written preceding the data to identify the appropriate conversion equation. For example, channel 050 was a type T thermocouple measuring primary hot water temperature to the engines. The equation $T°C = Am^4 + Bm^3 + Cm^2 + Dm$, where m is the millivolt measurement and A thru D are constants, was used for channel 050 and all type T thermocouple measurements. Another typical conversion was the signal from a differential pressure cell placed across a flow venturi. Channel 015 monitors the main PHW venturi. Pressure drop measured by the cell was described by $P = k\ (m - 2000)$ where m is the millivolt signal. The differential pressure was then used in the venturi flow equation $F = A \cdot B \cdot \gamma \sqrt{2gP}$ where A and B are constants unique to each individual venturi, and γ is the specific weight of the water which was calculated separately using the temperature measurement of channel 050, and g is the gravitational constant.

8. DAS AND INSTRUMENTATION COSTS

An accounting of the cost to implement the data collection system used to evaluate the performance of the JCTE site is presented in this section. All elements of the effort are reported in terms of dollars. Cost figures were derived from 3 sources; estimation of NBS in-house manpower, contracts awarded outside of NBS, and equipment purchases.

NBS in-house manpower costs were assessed by accumulating the amount of time spent by NBS personnel in the various activity areas, and multiplying by the appropriate salary received plus overhead.

Contracts to private firms were awarded for work done at the Jersey City site. Most equipment installation was performed by the on-site mechanical and electrical building contractors, under fixed price contracts. All site contractors used union labor. In most cases, building construction and installation of instrumentation were performed concurrently. Items making up a contractor's bid typically included labor, overhead and profit, and material not specifically supplied by the NBS. The amounts and descriptions of individual installation contracts are reported as cost items.

Amounts reported for equipment purchases from outside vendors are purchase prices of the DAS, transducers and discrete hardware elements. For hardware fabricated by NBS personnel, an estimated cost is given on labor and material expenses.

In order to reflect the composition of the total cost of implementing the JCTE instrumentation system, 3 major areas are defined. These areas are: system design (including equipment selection), equipment purchase and installation, and system checkout.

8.1 INSTRUMENTATION DESIGN COSTS

The design of the instrumentation system involved NBS manpower resources in several activities. Some time was devoted to familiarization with the Jersey City Total Energy plant and site design, and all pertinent documentation. Once data needs were defined the designation of transducer locations, and the selection of transducers among different types and manufacturers was performed. NBS worked with the DAS contractor to determine the optimum DAS configuration. Preparation of documentation of all instrumentation and DAS details was the final step before installation activities began. Design activities began in 1970 and continued through early 1973. The total expenditure for NBS in-house manpower devoted to instrumentation system design is estimated to be $516K.

8.2 EQUIPMENT PURCHASE AND INSTALLATION COSTS

The two major hardware areas are the DAS, and the instrumentation. The DAS is the data logger that sequentially selects signals from the CEB and remote building transducers and records digitized voltage values on magnetic tape. The instrumentation includes all mechanical and electrical transducers, any power source that provides electrical excitation for transducers, coupling cable between two or more transducers, any signal conditioning circuitry such as watt-hour integrating circuits, and signal cable from a transducer to the terminal strip where the signal voltage may be selected on a DAS data channel. Instrumentation costs are reported by measurement type.

8.2.1 DAS Cost

The purchase of the DAS was based on competitve bids submitted by vendors responding to technical requirements detailed in a DAS specification written by NBS. The monitoring of signals from the remote buildings, up to 700 feet from the CEB, made special demands on the capabilities of a data logging system. Monitor Labs of San Diego, California was awarded the contract to design and build a DAS for $50,000 in 1972. The hardware supplied included the chassis of the central station located in the CEB, namely, the clock, scanner, DVM, controller, tape drive and scanner slave. It also included eight remote stations, each consisting of multiplexing circuitry and an operational amplifier. Detailed documentation of all circuitry and cabling, and operational handbooks were also furnished by Monitor Labs.

8.2.2 Flow Instrumentation Costs

Water flow measurements on the TE site of greater than 200 lb/min utilize a venturi and differential pressure (Δ.p.) cell. NBS purchased all 31 venturi tubes with calibration curves from 2 vendors in 1972. The price of a venturi is generally dependent on the nominal pipe diameter and measuring capacity. For example, the purchase price for a venturi placed in a 3-inch pipe to meter a nominal 400 lb/min was $900, including calibration curves and constants derived from precision calibration tests. The largest venturi, 10-inch ID., metering 18,000 lb/min cost $2124. The average original cost for all 31 venturis with calibrations was $1275. Thirty one (31) differential pressure cells were purchased from ITT Barton of Industry, Ca., and were $566 each. The 5 pressure cells that monitor engine oil pressure, exhaust stack pressure and primary hot water system pressure, also, from ITT Barton, cost $520 each.

The 4 nutating disk meters that measured water and oil flow from 40 to 150 lb/min were purchased in 1976 at a cost of $260 each. Two meters measure fuel flow into the CEB day tanks, (manually read) and two are used for domestic hot water measurement in the school and Business Building. Approximately 15% additional was expended for repair parts.

The seven turbine meters used to meter 5 engine fuel flows and 2 boiler fuel flows were purchased with calibration information for $620 each in 1976.

Each flow sensor monitored by the DAS required an electronic interface that produced an electrical signal for the DAS. The CEB and the 7 remote site buildings each required one electronic power supply for differential pressure cells. The high amperage CEB supply cost $171. The smaller capacity building supplies cost $91. All were purchased in 1973. Turbines and nutating disk meters fed signal conditioning and integrating circuitry that was designed and fabricated by NBS. An estimated per data channel cost for electronics for 7 fuel turbines and 2 nutating disk meters is $250.

Mechanical installation of differential pressure cells consisted of mounting the cells and connecting each of two venturi ports to the cell inlets with 3/4 inch copper tubing, using 5 gate valves per cell. In the CEB, the contractor that constructed the building mechanical system installed NBS venturis and thermowells. Later, a separate firm installed 20 d.p. and pressure cells, not including electrical wiring, for a fixed price bid of $20,000. In the remote buildings, installation of NBS supplied venturis, d.p. cells, and thermowells, was performed under a single contract. In the remote buildings, the average cost for mechanical installation of 3 venturis, 3 d.p. cells, and 6 thermowells, was $5500 and was performed by the original building contractor in all cases.

The seven turbine meters on five engines and two boilers were installed by the CEB diesel engine service contractor for $2450. All four nutating disk meters were installed by NBS, at a total estimated cost of $1,000.

8.2.3 Temperature Measurement Costs

Hardware required for temperature measurements included: multipair thermopiles fabricated by NBS from thermocouple cable, 3/4 inch I.D. stainless steel wells and fittings, one electronic ice point reference for each site building, terminal strips, junction boxes, conduit and cable trough. NBS supplied all thermopiles and thermocouple cable to contractors. About 1250 feet of 16 pair thermocouple cable was used to fabricate 83, 16 pair thermopiles. Another 2250 feet of the cable were used to connect piles together for delta temperature measurements. The price for 3500 feet of this cable in 1973 was $2,000. 90 thermowells with fittings (7 were spares) were fabricated by the NBS shops at a cost of $50 per well. The 100 channel ice-point reference for all CEB temperature measurements cost $1890. Each of the seven ice-point references for remote buildings cost $685. Installation of temperature instrumentation is discussed in the next section.

8.2.4 Electrical Measurement Costs

Basic hardware required for measurement of electrical system parameters includes current transformers (CTs) and potential transformers (PTs), Hall-effect watt transducers, integrating circuitry for watt-hour measurements, and wire leads run in conduit from transformers to signal conditioning circuitry. Twenty watt transducers were supplied by NBS for all site power masurements at a cost of $180 each. Signal conditioning circuitry for all electrical signals was designed and fabricated at NBS, at an estimated per channel cost of $250.

All electrical installation on the site was performed by private construction contractors. Site electrical contractors installed all electrical transducers as well as wiring for flow and temperature transducers. In a remote building typical work included: purchase and installation on main power busses of 4 PTs and 4 CTs, wiring of PTs and CTs to a switch box and then to the NBS supplied remote cabinet, installation and wiring of six, 16-pair thermopiles, installation of an ice point reference, wiring of 3 d.p. cells, and termination of a 15-pair DAS multiplexing cable in the NBS remote cabinet. All cables were supplied by NBS and were run in conduit by the contractor. The contractor supplied all materials except thermopiles and cable. Work in the four residential buildings was similar in scope and cost. The average price for the electrical installation contracts in each of the seven site buildings was $7,200.

The main electrical installation contract for the CEB differed somewhat in scope from the remote building contracts. CTs and PTs had already been installed by the original building contractor. The secondary contractor made their connections to NBS electronics. Twenty pressure cells and 47, 16-pair thermopiles were wired and all signal cables run to the DAS terminal boxes. Approximately 1000 external DAS wire connections were made in the DAS room. Contractor-supplied material included all junction boxes, conduit for all cable runs, and all terminal strips and

special copper and constantan metal terminal lugs. The electrical contract for CEB instrumentation and DAS installation was awarded by HUD for $71,800.

8.2.5 Weather Station Costs

Weather station instrumentation costs for hardware totaled $3,268 for a wind speed and direction aerovane, aerovane tower, temperature and humidity sensors, two solar radiation sensors and signal conditioning electronics. Installation costs for mounting of the tower and connecting it to the building lightning protection system were $3,450.

8.2.6 NBS Manpower Costs

Very little actual installation of equipment was performed by NBS personnel. The use of NBS manpower resources was necessitated by the strict specifications for instrumentation installation at the JCTE site. Constant communication with the non-technically oriented construction contractors was essential to assure correct installation of transducers, and dealing promptly with field changes in order not to compromise measurement location or accuracy. Costs attributable to site installation activities are man hours for trips to Jersey City during site construction and travel expenses. Transportation and per diem expenses for a Monday through Friday trip in 1973 were approximately $200 per person, not including salary earned while in transit. Another NBS in-house activity that contributed to hardware installation costs was operational check out of new equipment received at NBS, before it was transported to the site. In most cases this involved the efforts of engineers and technicians who verified the correct operation of differential pressure cells, thermocouples, watt transducers and conditioning circuitry, and weather station sensors.

NBS installation activities were conducted from the time of ground breaking at the site in 1972 until completion of the last remote building electrical contract in early 1976. The total cost of NBS instrumentation installation activities is estimated to be $226K.

8.3 NBS CHECK OUT COSTS

Data system check out involved verifying that the installed instrumentation and DAS could perform the desired measurement and recording functions correctly. Some typical field activities were: field calibration of thermocouples and thermopiles using DAS voltage readouts, initial d.p. cell calibration, verification of correct remote building slave scanner multiplexing, comparison of manually-probed electrical power rates to DAS automated measurements, performing preliminary energy balance calculations and computer reading of raw data tape output to verify correct operation of the tape drive and data coupler.

The total cost of NBS field check out activities is estimated to be $200K.

EQUIPMENT COST TABULATION

DAS HARDWARE (Monitor Labs, San Diego, CA)

Chassis in central station rack - clock, DVM controller, scanner, tape drive, slave scanner

Remote station hardware consisting of multiplexing circuits and relays and operational amplifier. Eight remote stations supplied.

Fixed price contract, all hardware	$50,000.00

VENTURI FLOW MEASUREMENTS

HARDWARE

Venturis (Vickery Sims, Arlington, TX, and Badger Meter, Milwaukee, WI) with calibration information, 33 purchased for the TE site, 1972

Smallest, 3" ID = $900	
Largest, 10" ID = $2,124	
Average price = $1275 x 33	42,075.00

Differential Pressure Cell(ITT Barton, Industry, CA), one each per venturi, 34 purchased in 1972

Unit price $566	19,244.00

Power supply (Lambda, Melville, NY) for d.p. cell transmitters, 1 required in CEB, 1 each required in 7 remote buildings

CEB unit price	171.00
Remote Unit price $91	637.00

Electrical cable, NBS supplied, for wiring from DAS to d.p. cell

Cable, for TE site	200.00

Calibration pressure isolators, 2 each required per d.p. cell, 62 used on TE site

Design and development cost	4,000.00
Fabrication cost, per unit $20	1,240.00

INSTALLATION

CEB mechanical installation of 20 d.p. cells. Mount and connect d.p. cells, contractor supplies all piping material and valves.

Fixed price contractor with private contracting firm.	$19,000.00

Remote building mechanical installation - for each building install 3 venturis in water lines, mount and install 3 d.p. cells, install 6 thermowells. 7 separate site building installations contracted.

Average price, each building $5,500.	38,500.00
TOTAL FOR ALL SITE VENTURI FLOW MEASUREMENTS, HARDWARE AND INSTALLATION	$125,067.00

ELECTRICAL MEASUREMENTS

Watt transducers (Bell Inc, Columbus, OH) - purchased by NBS, 23 used for all CEB and site building measurements.

Unit price $200.	$ 4,600.00

Signal conditioning circuitry - designed and fabricated by NBS

Estimated per channel cost $150.	2,300.00

CEB Electrical Installation - install and wire 47 thermopiles, wire 20 pressure cells, install 3 watt transducer chassis, install DAS, install and wire ice point reference, wire turbine meters, supply all conduit and junction boxes

Fixed price contract	71,800.00

Remote Building Electrical Installation - contractor supplies and installs PTs, CTs, switch panel, wires d.p. cells, supplies all PT and CT wires, conduits, junction boxes, installs and wires thermopiles

Average price for each of 6 remote buildings $7,200	43,200.00
	$121,900.00

WEATHER STATION MEASUREMENTS

Hardware (Bendix Corp., Baltimore, MD) - Purchased by NBS in 1973, aerovane, temperature and humidity sensors, electronics, and aerovane tower (Rohn, Peoria, IL)

Total, weather hardware	1,588.00

Solar sensors (Eppley Laboratory, Newport, RI) - one direct, one indirect

Total for solar sensors	1,680.00

Installation - Mount tower, route extra cable, tie in to lightning protection grid

Fixed price contract	3,450.00
WEATHER STATION TOTAL	$6,718.00

NUTATING DISK METERS (Badger Meter, Milwaukee, WI)

Meter - 4 each purchased by NBS for 2 domestic hot water measurements and 2 fuel oil measurements

Unit price $260 X 4	$1,040.00
Installation - performed by NBS. Estimated total cost	1,000.00
TOTAL, HARDWARE AND INSTALLATION	2,040.00

OMNIFLO TURBINES (Flow Technology Inc, Phoenix, AZ)

Meter - 7 purchased by NBS for fuel measurements, with calibration information

Unit price $620 X 7	$4,340.00

Installation - on 5 engines and boilers performed by the CEB diesel service contractor. Wiring by NBS	
Fixed price contract	$2,450.00
Signal conditioning electronics - designed and fabricated by NBS	
Estimated total cost for 7 measurements	1,750.00
ITT Barton Turbines (Monterey Park, CA)	
15 turbines. Total cost	$8,800.00
Total for Turbine Measurements, Hardware and Installation	17,340.00

TEMPERATURE MEASUREMENTS

Thermopiles - 83 used on TE site. Cable used for pile fabrication purchased by NBS in 1972.	
Total cost	$ 710.00
Thermopile Fabrication - 16 junctions welded per pile by NBS	
Estimated cost, 83 thermopiles	2,000.00
Thermowells and fittings - one well per thermocouple plus 7 spares, fabricated at NBS shop. Unit price $50 x 90	4,500.00
Ice point references (Kaye Instruments, Cambridge, MA) - purchased by NBS, 1972	
100 channel unit for CEB	1,700.00
6 channel unit, 7 required for remote buildings. Unit price $685	4,795.00
Connection and signal cable - for connections between thermopiles, and for signals to DAS and ice point references	
All cable for TE site	1,800.00
	$15,505.00

GRAND TOTAL $338,570.00

9. SENSOR SELECTION AND ACCURACIES

The accuracy goals for field measurements were 1% or better at the sensor output plus 1% or less degradation for signal conditioning and processing yielding a recorded accuracy of 2%. Signal conditioning refers to signal attenuation, amplification and wave shape changes. Signal processing applies to signal integration, multiplication, voltage to frequency (V/F) and frequency to voltage (F/V) conversions.

Flow Measurements

The choice of instruments for fluid flow measurements were venturis, turbines, nutating disk meters and target type meters. With the exception of the venturi, the signal generating components of the flow meters were in the fluid stream and in the event of an instrument failure the flow had to be stopped or by-passed around the meter to remove the defective instrument, whereas the venturi is a relatively simple (though precise) pipe section with small ports drilled in the casting to permit pressure measurements.

The water distribution pipes at the Jersey City site varied from 3" to 12" in diameter with flow rates from 170 gpm to 2500 gpm. The addition of by-pass plumbing and valving for the large water pipes would have created plumbing line clearance problems and increased contractor installation costs. Venturies were available with calibration curves assuring 0.5% accuracies and their use would obviate the need for by-pass plumbing, therefore, the venturi was considered the best device for measuring the high flow rates in the primary, secondary and chilled water loops. The parameter that was measured in the venturi was differential pressure (ΔP) and the flow rate was calculated by the computer by inserting the value of ΔP into the venturi flow equation. The ΔP across the venturi was measured by a transducer that provided a DC signal proportional to the ΔP. Manufacturer's stated accuracy for the pressure transducer (Δp cell) was 0.5% and repeatability was 0.2%. The ΔP cells were periodically calibrated in the field to 1% accuracy. Venturi signals originating in the CEB were carried directly to the DVM and digitized. The DVM could contribute a maximum 0.1% error in the conversion process. The signal path from the DVM to the tape recorder was simply data transfer and did not affect the signal magnitude.

ΔP cell signals generated at the remote buildings had a stage of signal conditioning added between the transducer and the DVM. The signal was attenuated in a resistive divider network and amplified by an operational - amplifier (this signal path is evident in the drawing in section 4.2). The op-amp gain accuracy was 0.01% and was field calibrated to 0.1%. Amplifier errors due to the zero shifting with time and with temperature changes were cancelled out during the data processing phase. Every remote station provided a channel with a shorted input to the op-amp. The signal level recorded for this channel was applied as a correction factor during the data reduction phase.

Considering a worst case condition, the accuracy of a venturi pressure measurement from the CEB to the tape recorder was 1.0% (transducer) + 0.1% (DVM) = 1.1% and from a remote building was 1.0% (transducer) + 0.1% (DVM) + 0.1% (conditioning circuits) = 1.2%.

The initital measurement system determined fuel consumption by measuring the difference in fuel oil flow between the supply and return lines that connect the fuel day tanks to the engines and boilers. Figure 23 illustrates the fuel flow path and location of the turbine meters in each day tank fuel line. Though the turbine specifications indicated a 0.1% accuracy and a 0.02% repeatability, considerable error was experienced in the fuel measurement. A new metering system capable of measuring consumed fuel directly was substituted for the original flow-difference measuring technique. The present measuring system uses a turbine in each engine's fuel injection line and a turbine in each boiler nozzle. A discussion of the fuel measurement problems and their solution is included in section 10.3.

Fuel flow rates, going directly into an engine or boiler, ranged from 0.4 to 1.5 gpm and the turbine was the only sensor that offered a 0.5% accuracy in the lower than 1.5 gpm range with a repeatability of 0.1%. The turbine meter was also an attractive choice because it produces a sinusidal signal suitable for electronic conditioning. The fuel parameter of interest was not the flow rate but the fuel consumed. The turbine is a volumetric device that indicates the number of volume units (counts) that pass through the turbine. The computer had to multiply the total counts by a coefficient (K factor) to yield gallons consumed. The turbine signal was processed through a F/V converter that totalized (integrated) the transducer signal (figure 26) and produced a DC level proportional to the volume of fuel consumed. The accuracy of the consumed fuel measurement with a 1.0% factory calibration was:

1.0% (turbine) + 0.1% (F/V) + 0.1% (DVM) = 1.2%

In order to provide a long term accumulative total of fuel use, two nutating disk meters were installed in the day tank refill lines. Each meter was equipped with a mechanical register that totalized to 10 million gallons. These meters were calibrated at the NBS to a 1.5% accuracy.

Turbines were initially installed in the business building and school to measure water flow in the 20 gpm range. The turbine rotors became encrusted with mineral deposits carried by the water. Filters were added to combat this problem but they would clog up after two weeks of service, so nutating disk meters were substituted for the turbines. The nutating disk meters were not as demanding of filtered and particle free fluids. They were equipped with relay contacts to adapt them to automatic data logging systems. Each meter had a 1.5% accuracy over its operating range. Meter contact closures were sensed and the signal processed by a circuit that is identical to the F/V unit described above for turbine fuel measurements.

The disk meter is also a volumetric device and the processed signal represented the volume of water passed through the meter. The accuracy of the water volume measurement was:

1.5% (disk meter) + 0.1% (F/V) + 0.1% (remote op-amp) + 0.1% (DVM) = 1.8%

Electrical Power Measurements

Since the parameter of interest, in the electric system was kilowatt-hour (kW-hr) consumption, the selection of a transducer focused on a device that would measure power (watts) and lend itself to a straightforward approach to computing (electronically) kilowatt hours. A class of power measuring transducers that had recently become available was the Hall-effect type. This transducer produced a DC voltage that was proportional to the measured AC power. The DC voltage would be processed to represent kW-hrs and recorded by a data logging system. The Hall-effect electrical power transducer had a manufacturer's specified accuracy of 0.5%. The transducers were calibrated in the field (after installation) to 1.0%. All power measurements were made with Hall-effect transducers. The output signal was processed into a kilowatt-hour signal (see figure 16) and recorded on tape. The processing circuits consisted of a V/F converter accurate to 1 count out of 500 or 0.12%, and a digital to analog converter (F/V) consisting of 256 steps for a 5 volt maximum output signal. The maximum uncertainty the DAS could encounter when sampling this output voltage was one step or .4% (5/256 = 20 millivolts out of 5 volts). The accuracy of a kilowatt-hour measurement made in the CEB was:

1.0% (transducer) + 0.2% (V/F) + 0.4% (F/V) + 0.1% (DVM) = 1.7%
and in a remote building:

1.0% (transducer) + 0.2% (V/F) + 0.4% (F/V) + 0.1% (op-amp) + 0.1% (DVM) = 1.8%

The electrical power measurement in several remote buildings exceeds the 1.8% error due to line loading conditions that are discussed in section 10.1.

Temperature Measurements

Ninety-six points were designated for temperature measurements at the total energy site. Fifty-five measurements were actual temperatures and forty-one differential temperatures. Since a large quantity of temperature sensors had to be assembled, the thermocouple sensor was chosen for its simplicity, ruggedness and ease of fabrication. The problem of low signal levels, encountered when measuring small differential temperatures was met by constructing 10-pair thermopiles which increased the signal level by a factor of ten. The non-linearity of the thermocouple elements (90% were type T, copper - constantan, 10% were type J, iron - constantan) posed no problem since the DAS recorded only the potential level of the thermocouple and the computer calculated the corresponding temperature. The accuracy of the temperature measurement was a function of the

homogeneity of the metal wire, the accuracy of the reference junction, the terminal junction at the meter and the properties of the medium in which the sensor is immersed. The American Standard for Temperature Measurement Thermocouples (C96.1 - 1964) lists the special limits of error for type T, copper - constantan, in the - 70°F to 200°F range at ± 0.75°F. Thermocouple manufacturers consider this table of "limit of error" to be a practical maximum.

The total maximum error for a thermocouple measurement would be 1.5°F; 0.75°F at the measurement junction and .75°F at the reference junction. This maximum error applied to a PHW measurement at 180°F and a chilled water measurment at 45°F would represent 0.8% and 3.5% errors respectively. The maximum error in recorded value would be:

PHW = 0.8%(thermocouple) + 0.01%(reference temp.) + 0.1% (op-amp) + 0.1%(DVM) = 1.01%

Chilled Water = 3.5%(thermocouple) + .01%(ref. temp.) + 0.1%(op-amp) + 0.1% (DVM) = 3.75%

Each thermocouple data channel was calibrated at the site (after installation) by immersing the thermocouple into 33°F and 80°F liquids. The liquid temperature was measured by a thermometer certified to a 0.2°F accuracy. The thermocouple voltage levels were recorded from the digitizing voltmeter in the DAS. The final voltage reading included all terminal connection and wire length affects. Every thermocouple channel correlated to within 1.0% of the reference thermometer.

Another factor that has an effect on the accuracy is the temperature probe location. The thermocouples were inserted in stainless steel walls that protrude into the water stream. Since the thermocouple was not in direct contact with the water the thermal conductivity of the steel well and the silicon rubber that insulates the tip of the thermocouple enter into the temperature measurement. The time constant effect of the different materials between the thermocouple and the water was not explored. However, the characteristics of the circulating water loops at the total energy site were such that the temperature of the water loops was not subject to abrupt change and the flow-rates could be considered constant.

Possible errors introduced by the well configuration, well material or heat conduction from thermocouple to well wall was not explored.

Weather Station

The weather station components were manufactured by Bendix-Friez Co. and were furnished with the following manufacturer's stated operational accuracies:

Barometric Pressure: An aneroid barometer device measuring 27 to 31 inches of mercury to an accuracy of 0.5% of reading.
Data channel accuracy = 0.5% (transducer) + 0.1% (op-amp) + 0.1% (DVM) = 0.7%

Air Temperature: Thermister probe. Accurate to 1.5% of reading from -20°F to +120°F.
Data channel accuracy = 1.5% (probe) + 0.1% (op-amp) + 0.1% (DVM) = 1.7%

Humidity: Accuracy is 3.0% of reading from 30% to 70% RH.
Data channel accuracy = 3.0% (transducer) + 0.1% (op-amp) + 0.1% (DVM) = 3.2%

Solar Radiation: Accuracy is 3.0% of reading. Range from 0 to 2.0 cal/ cm^2 min.
Data channel accuracy = 3.0% (transducer) + 0.1% (op-amp) + 0.1% (DVM) = 3.2%.

Wind Velocity: Aerovane accuracy is 2.0% of reading from 0 to 100 mph.
Data channel accuracy = 2.0% (aerovane) + 0.1% (op-amp) + 0.1% (DVM) = 2.2%

Wind Direction: Aerovane accuracy is 2.0% of reading from 0 to 360 degrees.
Data channel accuracy = 2.0% (aerovane) + 0.1% (op-amp) + 0.1% (DVM) = 2.2%

10. INSTRUMENATION PROBLEMS

10.1 ELECTRICAL MEASUREMENTS

Several problems were encountered in electrical measurements. Complicated wiring schemes and inaccesible locations for the potential transformers, current transformers and the main power transducer, made the calibration and servicing of the electrical measurement system a difficult task. As a result of the wiring method, it was very difficult to service the NBS electrical power transducer which measured total generated power. The plant design specified a single set of current transformers on the main power bus to feed the engine control system transducer, the NBS gross power transducer, the plant total power kilowatt-hour meter and the plant strip-chart recorder. As a consequence, all of these devices were connected in a series fashion to the main current transformers so that maintenance on any one of these four devices affected the functioning of the other devices. The transducers could be switched out of the system for calibration or service and our experience when replacing an original power transducer without shutting down the entire plant required awareness that transducer servicing with "hot" power busses is a delicate and potentially hazardous procedure. The original power distribution design should have incorporated shorting switches across each measuring device to facilitate the safe and easy removal of malfunctioning instruments. For further safety and flexibility, each transducer should be serviced by a separate set of current and potential transformers. Whenever possible, when maintenance is to be performed on any of these four devices it should be scheduled to coincide with an electrical plant shut down.

Several current transformers, used with the power transducers to measure building electrical loads, were changed to units with lower turn ratios. The original CT's were chosen on the basis of early building load estimates. These estimates proved to be too high. The new current transformers were installed during scheduled building power shutdowns.

Problems were encountered in the analysis of building electrical loads. A comparison of the electrical power delivered by the CEB to the remote buildings with the summation of each building's power consumption varied from 1.0% to 15.0%. A detailed thorough inspection of the actual building wiring and load distribution systems revealed that the power distribution system differed in each building. Normally, the electrical power loads on the essential power bus would be; elevators, fire pumps, stairwell lights and fire alarms. The remaining electrical services would be on the normal power bus. The Shelley A building had one elevator on the essential bus and the other elevator on the normal power bus. The same condition existed at the Descon building. The single elevator in the business building is powered by the normal bus. These situations are a result of different electrical contractors working on each building. The electrical wiring in the Camci building was installed by two independent contractors. The substantial deviation of electrical loading from early estimates had an impact on the power measurement system. The watt transducers originally chosen for the building power measurements were two element devices which monitor the current in two lines of a three phase circuit. This instrumentation is accurate for a constant potential and balanced load condition. The constant potential condition is maintained at the buildings at all times. However, load unbalances of 30% were occurring for several hours during the day. Wherever feasible, three element watt transducers were installed. In the Shelley A, Descon and Camci buildings, the addition of a third current transformer (to accommodate a three element transducer) was not feasible since access to the primary feeder bus would have required the disassembling of a power distribution cabinet and would have required a building power shutdown for several days.

In a total energy environment, it is desirable to separate the gross electrical power generated to two parts (1) the electrical power used in generating the power, commonly known as parasitic load; and (2) the electrical power that would have been purchased from the public utilities if the plant were not generating its own electrical power. With the existing motor control center wiring at the Jersey City Total Energy Site, the loads parasitic to the generation of electrical power could not be directly measured. In most cases, local electrical codes and regulations made it necessary for the contractor to feed both parasitic generation loads and HVAC loads from the same motor control center. For example, the motor control center which received essential power, MCC-1, supplied most of the parasitic generation loads to facilitate restarting the plant in the event of an outage, however, codes required the boilers to be placed on this same motor control center. Secondary hot water pumps, and house pumps were also supplied by this same motor control center thereby mixing the HVAC and parasitic electrical generation loads.

A major redesign would be required to separate the motor control centers to allow direct measurement of the parasitic loads. The cost of the necessary changes was judged not compatible with the measurement objectives. Instead, these loads were determined indirectly by the computer. The computer program examines thermal data to assess the on/off state of individual plant HVAC equipment and predicted the cumulative hours of individual operation. The electrical power demand of the equipment (determined from voltage and current measurements made at the equipment) was multipled by hours of operation to determine the kilowatt-hours consumed by plant HVAC equipment. Parasitic electrical loads were determined from the difference between the total motor control center demand and the HVAC demand.

Similar problems have been encountered in allocating the plant electrical air compressor loads between the electrical plant controls and the pneumatic trash collection system (PTC). One system supplied compressed air for the diesel engine starters, for some engine controls and for the PTC controls. Due to large line leak losses in the PTC control system the allocation of the compressor electrical power between the operation of the electrical plant and PTC was difficult. Fortunately, the electrical loads of the two air compressors with 15 horsepower motors were small relative to the continuous parasitic loads of the primary hot water loop circulating pumps and the intermittent loads of the 150 HP motor of the PTC exhausters. These loads made the exact allocation of the compressor loads insignificant.

10.2 WATER FLOW MEASUREMENTS

Measurement problems were encountered in the differential pressure (Δp) cell systems (monitoring the primary hot water flow) within a month of initial installation. Foreign particles collected in the bellows of the Δp cell causing the instrument to offset to a maximum reading or affecting the linearity of the instrument. Figure 50 is a photograph of a debris laden bellow assembly.

The problem of foreign material building up in the folds of the bellows was relieved by installing bleed lines on both sides of all differential pressure cells as shown in Figures 18 and 19. The bleed lines were installed so that sediment collecting in the pressure lines could be flushed by opening the bleed valves and allowing the water flowing through the venturi to flush out the lines and the annular rings in the venturi. Flow rates that exceeded the range of the Δp cells occured in the secondary hot water (SHW) lines in Camci and Shelley A buildings after the first year of operation. The cause was traced to a building action. The original 450 gpm hot water pumps failed and were replaced by larger 750 gpm units. To accommodate the higher flow rates, pressure transducers with larger dynamic ranges replaced the original units.

Problems were encountered in the two instances (school and business building) where turbines were originally installed to measure flow to the domestic heat exchangers. Sediment in the water clogged the turbines. Filters were installed to remove the sediment and particles

upstream from the turbines. However, the filters became clogged after a few days of service. As a final solution, a nutating disk flow meter, a type of meter more tolerant to unfiltered liquids, was substituted for the turbines.

To insure the integrity of the Δp cell measurement an in situ calibration procedure was realized through the design of an interface device (items B in figure 19). The interface device transfers an externally applied differential air pressure through an isolating diaphram to the water filled Δp cell. The differential air pressure is varied over the design range of the cell and the signal output level is recorded to assure that the cell is maintaining a 1.0% accuracy. The calibration procedure requires the closing of the venturi line valves and connecting the air pressure source. After calibration the venturi line valves are opened and the air source is disconnected. A calibration is performed each month. Figure 52 is a photograph of the portable test unit used to calibrate the Δp cells.

10.3 FUEL OIL FLOW MEASUREMENTS

The only systems consuming fuel oil at the TE site were the diesel engine system (five engines) and hot water boiler system (two boilers). These systems are commonly designed to draw their fuel from a constantly circulating fuel supply, therefore each system at the site had a fuel supply line and a fuel return line (figure 23). Approximately 15.0 gallons of fuel per minute flowed through the engines' supply line and 13.5 gallons per minute (gpm) flowed through the return line, the difference being the fuel used by the diesel engines. The boiler fuel system operated with a fuel flow rate in the 12 gpm region. In the initial measurement system, turbine meters were used to measure the total supply and return rates to the engines and boilers. The engine and boiler fuel consumptions were then calculated by the computer by subtracting the return flow rate from the supply flow rate. When the fuel consumption calculations, derived from the recorded data, were compared against fuel delivery invoices discrepencies of 15% appeared, which required resolution. Arrangements were made to return the turbines to the manufacturer for a recalibration. In order for the fuel measurement system to yield a 1.0% accuracy, using a supply and return scheme, the turbine meters must be capable of calibration to an accuracy of 0.1% or better. An average of 1.5 gpm of fuel are consumed when three diesel engines are in operation. With a 15 gpm flow in the supply line the return line would carry a 13.5 gpm flow rate. Assuming a one percent error in the supply turbine (the measurement would indicate 15.15 gpm) and no error in the return turbine, the consumed fuel calculation would be: 15.15 gpm (supply) - 13.5 gpm (return) = 1.65 gpm. This is a 10% error over the actual 1.5 gpm. A 0.1% error in the supply turbine measurement would reflect a 1.0% error in the calculated fuel consumption; 15.015 gpm (supply) - 13.5 gpm (return) = 1.515 gpm, $\frac{1.515 \text{ gpm} - 1.5 \text{ gpm}}{1.5 \text{ gpm (actual)}} = 1.0\%$. The required measurement accuracy was within the operational capability of all the supply and return turbines used at the total energy site. It took the

manufacturer several months to complete the calibrations. In the meantime NBS explored the feasibility of metering the fuel as it went directly into the Diesel engine cylinders and into the boilers. A metering point was identified in the engine fuel injection system and new turbine meters (from a second manufacturer) designed to measure flow rates in the 0.1 to 1.0 gpm range, were purchased and installed in each diesel engine. Technical discussions with the boiler manufacturer indicated that a direct fuel measurement could be made in the line supplying fuel to the boiler nozzle. New turbines rated from 0.2 to 2.0 gpm were installed in the boilers. As a further check on the fuel feed system, nutating disk meters with totalizing mechanical registers were installed in the two CEB day tank fuel lines figure 51 (one tank supplied the engines,the other tank supplied the boilers). These were 1000-gallon tanks that were frequently topped with approximately 12 gallons of fuel every seven minutes. When the recalibrated total supply and return turbine meters were returned from the manufacturer and reinstalled, and the fuel measurement data examined, discrepancies of 10% were still present so the turbines were taken to the NBS and calibrated at the fluid mechanics laboratory. The NBS "K" factors (the calibration factor "K" = pulses per gallon) were 8 to 14% higher than those submitted by the manufacturer. Using the NBS calibration the supply and return method of fuel measurement agreed with the day tank measurement to within 2.0%. Though the engine fuel consumption is determined from the direct engine measurement, the performance investigation of the return and supply method was pursued to verify that this method can yield accurate measurements since many fuel supply systems are accessible only at the supply and return lines. The factor that was clearly demonstrated by this exercise in fuel measurement was that when instrument calibration demands enter the fraction of one percent region, it is necessary to use calibration equipment and procedures capable of this accuracy.

10.4 TEMPERATURE MEASUREMENTS

During the data checkout phase of the temperature measuring system examined variations were noted in the differential temperature measurement (PHW) across engines one and two. These variations were greater than expected when compared against the total engine bank differential temperature.

The two temperature variations were traced to cooling effects at the top of two thermowells caused by cold ventilation air blowing directly across the thermowells. The thermocouple wells for engines 1 and 2 are directly under a chilled air grating. Subsequent examination of the data showed that the variations in T, which could be caused by the cooling air was 2°F. This represented a 15% error during the periods when ventilating fans were in operation. The effects of the ventilating air was completely eliminated by improving the thermal insulation on engine 1 and 2 thermocouples (figure 27). As a consequence of identifying this localized temperature measurement error, NBS insulated or reinsulated every thermowell in the site to determine if any other temperature anomalies existed. An analysis of site thermal data for January 1976 to September 1976 (insulation was installed in September 1976) and October 1976

through September 1977 indicated that the additional insulation applied to the CEB thermowells had no effect on the temperature measurements. Of the 54 actual and 42 differential thermocouple temperature measurements, two T measurments were found to be in error due to an immediate-area environmental influence.

10.5 ENGINE-GENERATOR ALARM INSTRUMENTATION

The engine-generator alarm instrumentation was not fully utilized in data monitoring because of two problems. First, the alarm instrumentation sensed signals from malfunction sensors which were energized by engine control circuitry only when the engine was operating at greater than 90% of rated speed. The engine alarm circuitry had no memory capabilities, so that, when an engine's speed dropped below 90% of operating speed all alarm sensors were de-energized and could not be sensed by the DAS. Unless the DAS was recording the alarm data at the exact instant the malfunction signal was occurring (before an engine dropped below 90% speed), the alarm data was not recorded. (An engine control system also displayed all alarms only while an engine was running above 90% speed). Ideally, engine malfunction signals should be available for DAS recording and for the plant indication whether or not an engine is above 90% speed.

Modifications to the engine alarm system to correct those shortcomings had been under consideration by the plant operator but were not implemented.

10.6 GENERAL REMARKS

Site measurement problems experienced can be divided into three categories: (1) Problems caused by difficulties in relaying instrumentation installation instructions with proper authority to the site contractors and inadequate control of the quality of workmanship associated with the installation of the instruments, (2) Problems resulting from field environment and (3) System alterations made by maintenance personnel.

Construction management of the site was initially awarded to Volt, Inc. who supervised the electrical and plumbing contractors. Instrument installation instructions and changes were coordinated through the construction manager and, on several occasions, through the local unions. Many of the building contractors had no previous experience in the installation of precision instruments. Site construction was approximately one third complete when management of site construction was awarded to the Boeing Corp. Much of the non-uniformity in electrical load distribution within the buildings, with a consequent impact on measurement accuracy resulted because of the difficulty in monitoring and directing installation at the workman level.

Site environment had an impact on thermal and water flow measurements. Ventilating air affected two temperature measurements and foreign matter in the hot water loops fouled several pressure cells. As these problems were discovered, corrective action was instituted.

Large changes in system operation characteristics (large increase in water flow rates) caused by maintenance personnel substituting over-rated or under-rated components for defective units caused transducers to malfunction by exceeding their operational range. This problem could have been avoided if such equipment repair and adjustment had been coordinated with the measurement personnel.

Acknowledgements

This project, from its conception to the time of this report, has covered more than a five year period. During this time many NBS engineers and managers have contributed towards its progress. Those whose contributions have been particularly significant during one or more phases are mentioned below as an expression of the author's gratitude.

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L. Galowin, Section Chief, Building Services Section
J. Snell, Manager, Energy Conservation Programs
C. W. Phillips, Manager, NBS/HUD-MIUS Program

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J. B. Coble

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For installation and checkout support:

J. R. Graves
L. Brammer
J. Cohen
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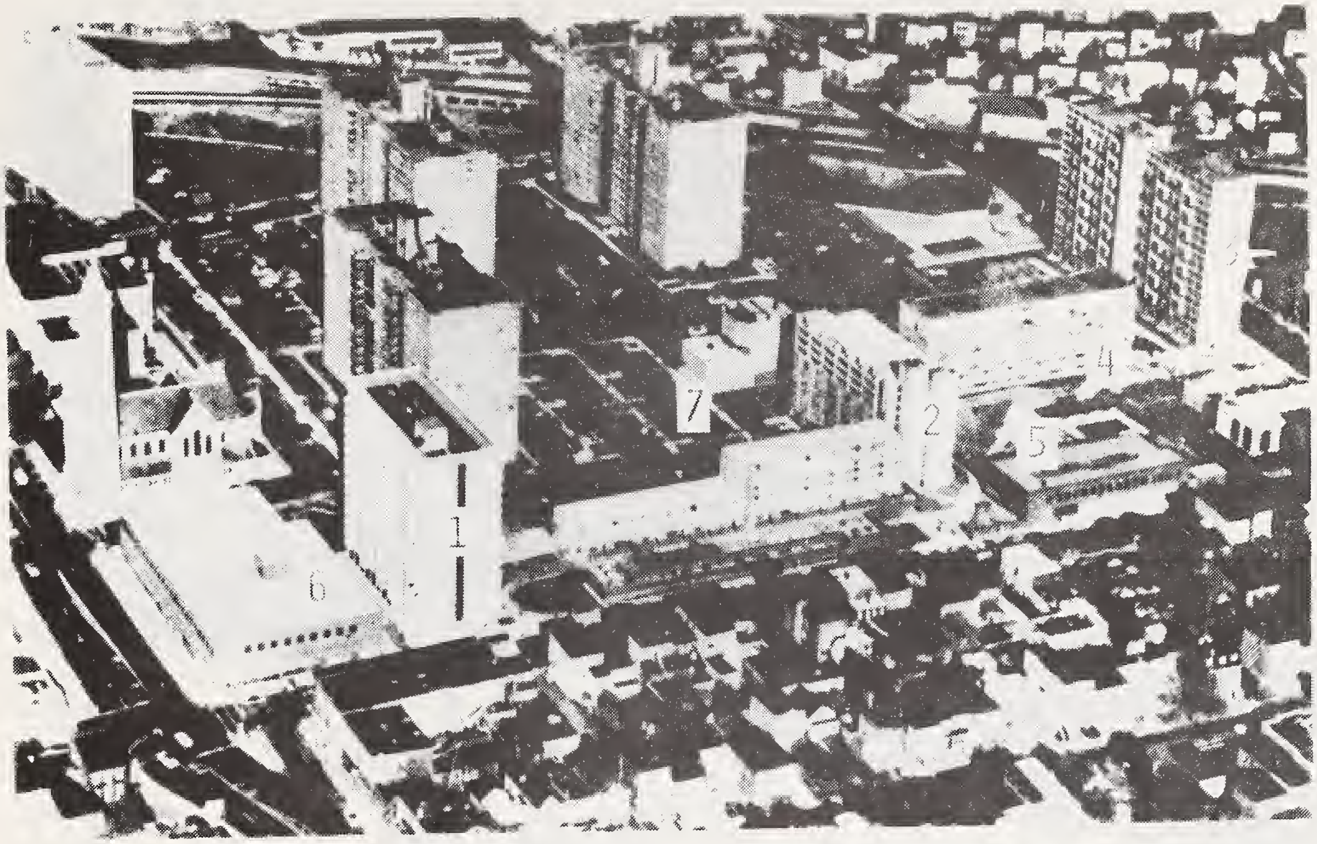

Figure 1 An aerial view of the Jersey City Total Energy Site. The four apartment buildings are Camci (1), Descon (2), Shelley A (3), Shelley B (4). The school (5), commercial building (6), and plant (7) are also indicated.

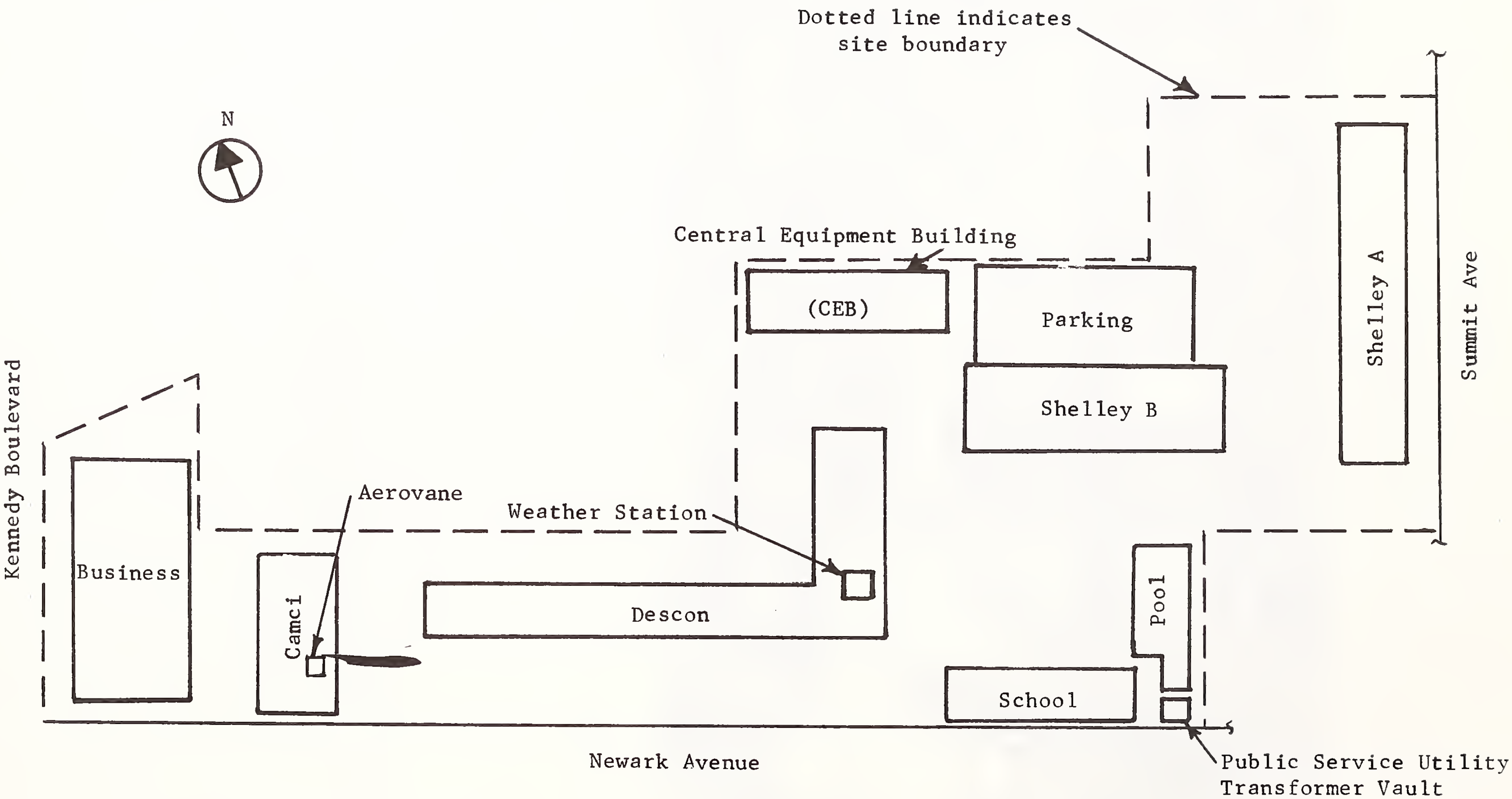

Figure 2 Plan view of the Total Energy site. Building names refer to the designing companies

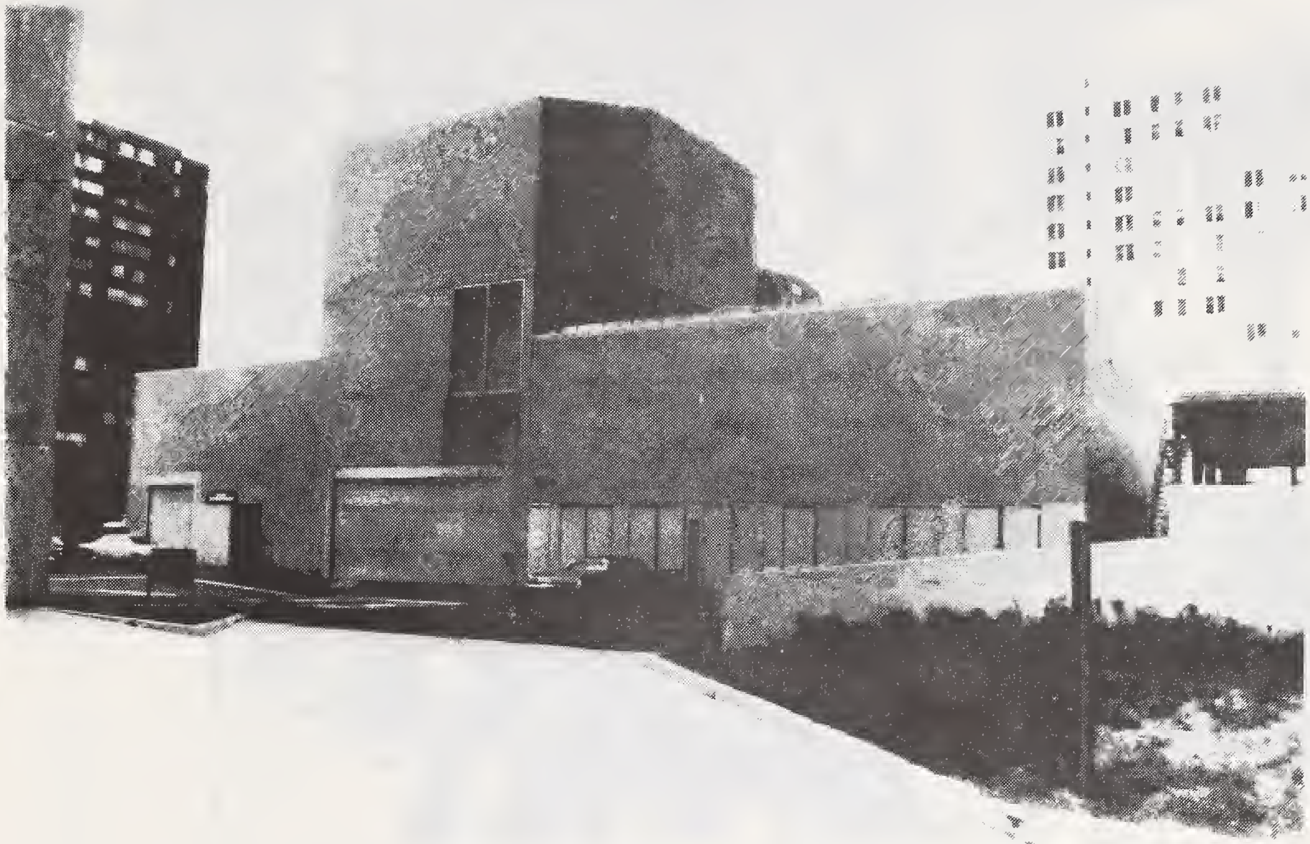

Figure 3 The central equipment building which houses the total energy plant. Five engine-generators are located behind the six pairs of doors. The central section has a large door for access to the trash collection system. Above the doors are air intakes for plant ventilation. In the top central section behind an accoustic screen are the chiller cooling towers. The boilers and chillers are located in the left-most section.

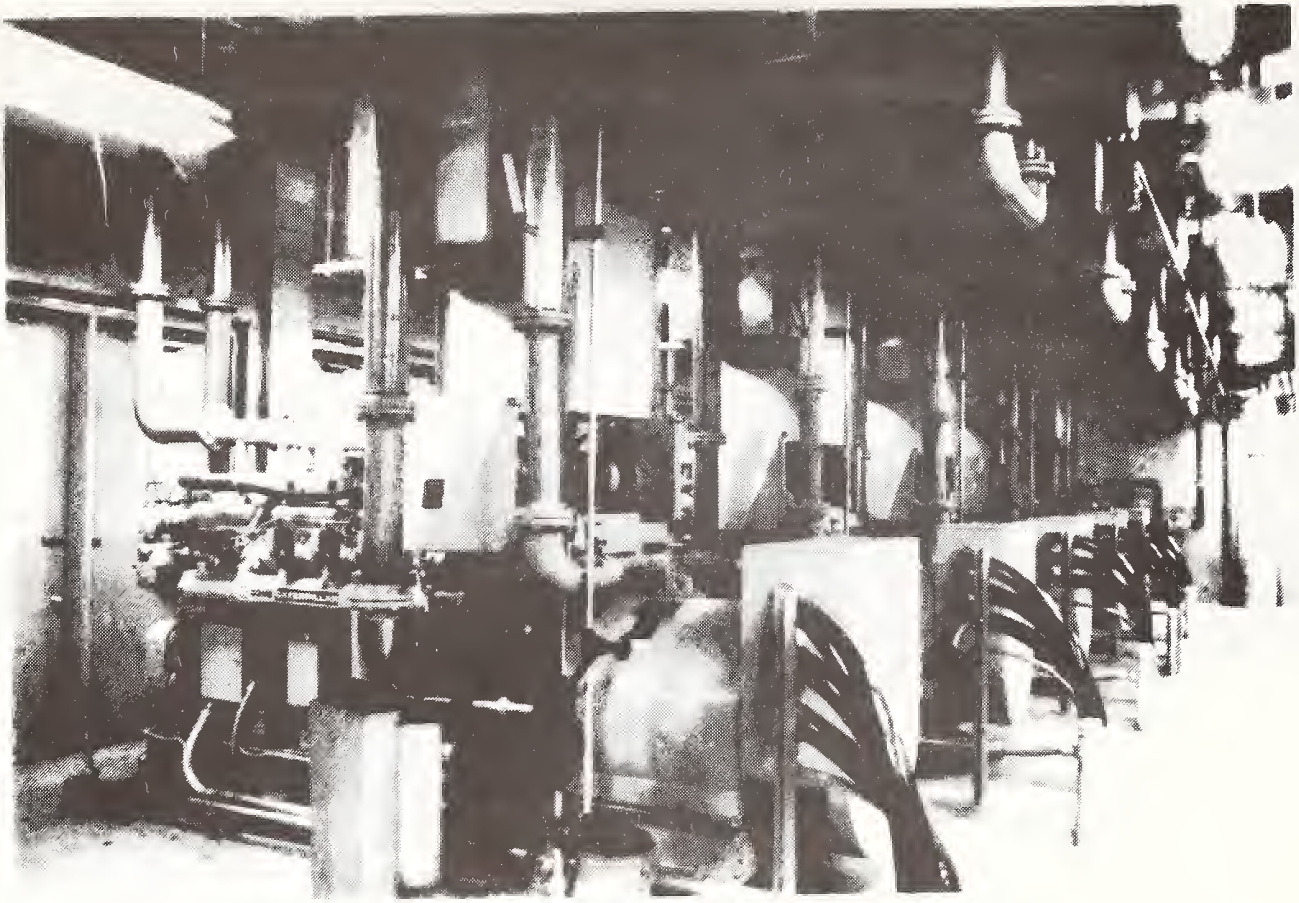

Figure 4 The bank of five diesel engine-generators. The sets of three large cables connect each generator to the main power bus. Heat recovery exhaust exchangers are located above the engines.

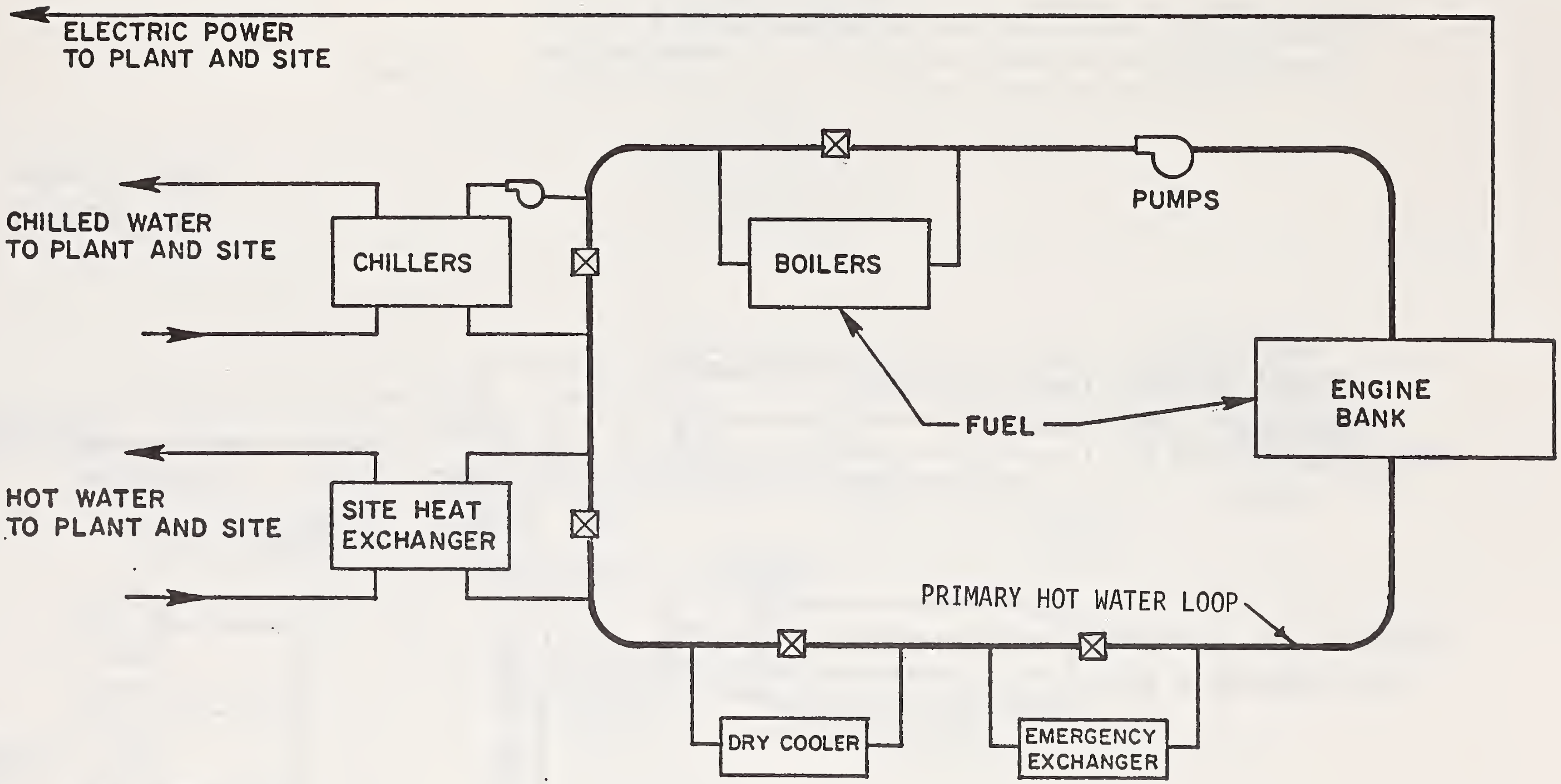

Figure 5 Schematic of the Primary Hot-Water Loop showing the major components connected to the loop and the sequence of primary water flow through them. Balancing valves are also shown.

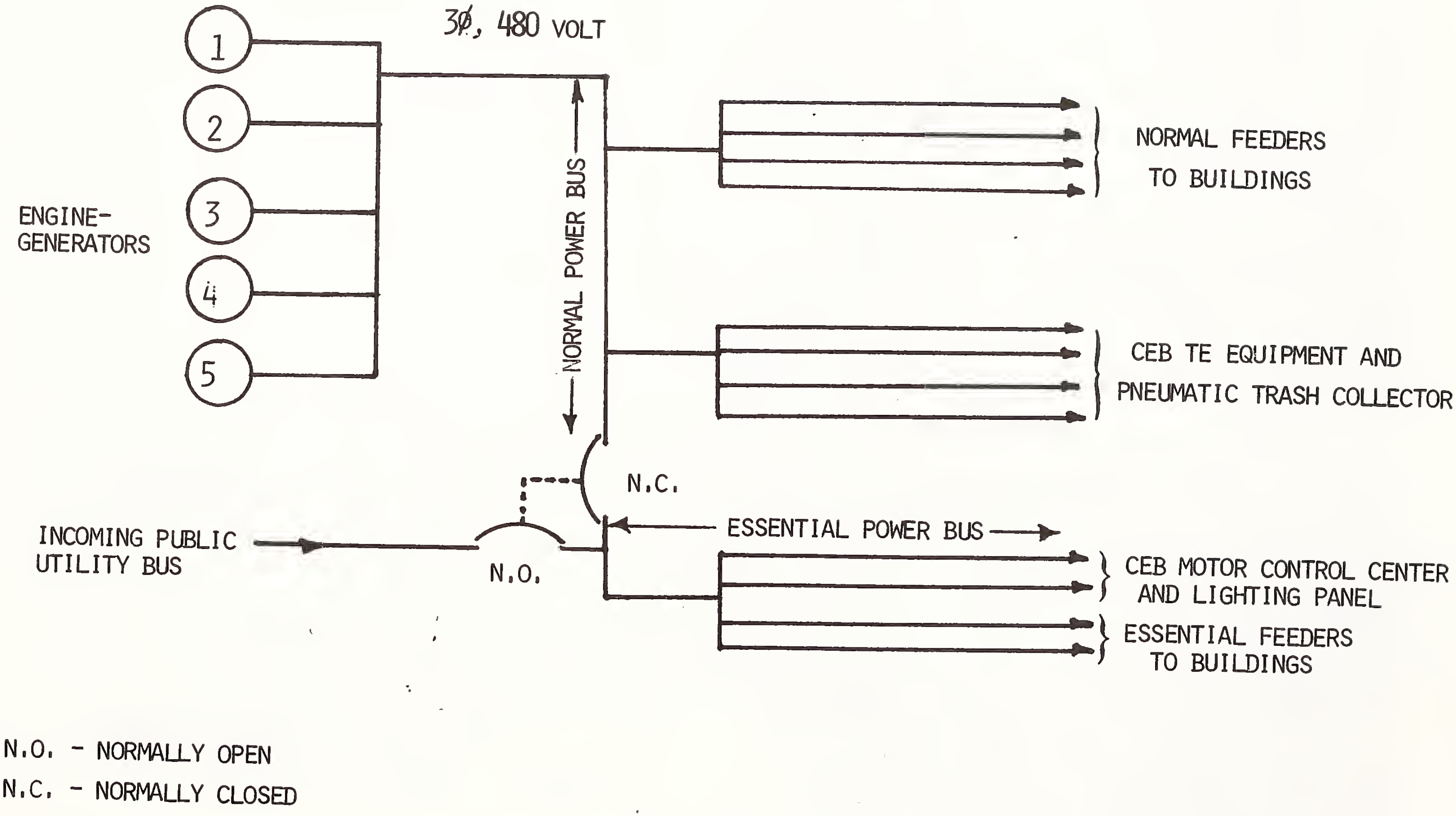

Figure 6 Total Energy plant electrical power distribution. Engine-generators normally provide all site electricity. In the event of engine failure automatic circuit breakers disconnect plant generators and connect the public utility power to essential site loads.

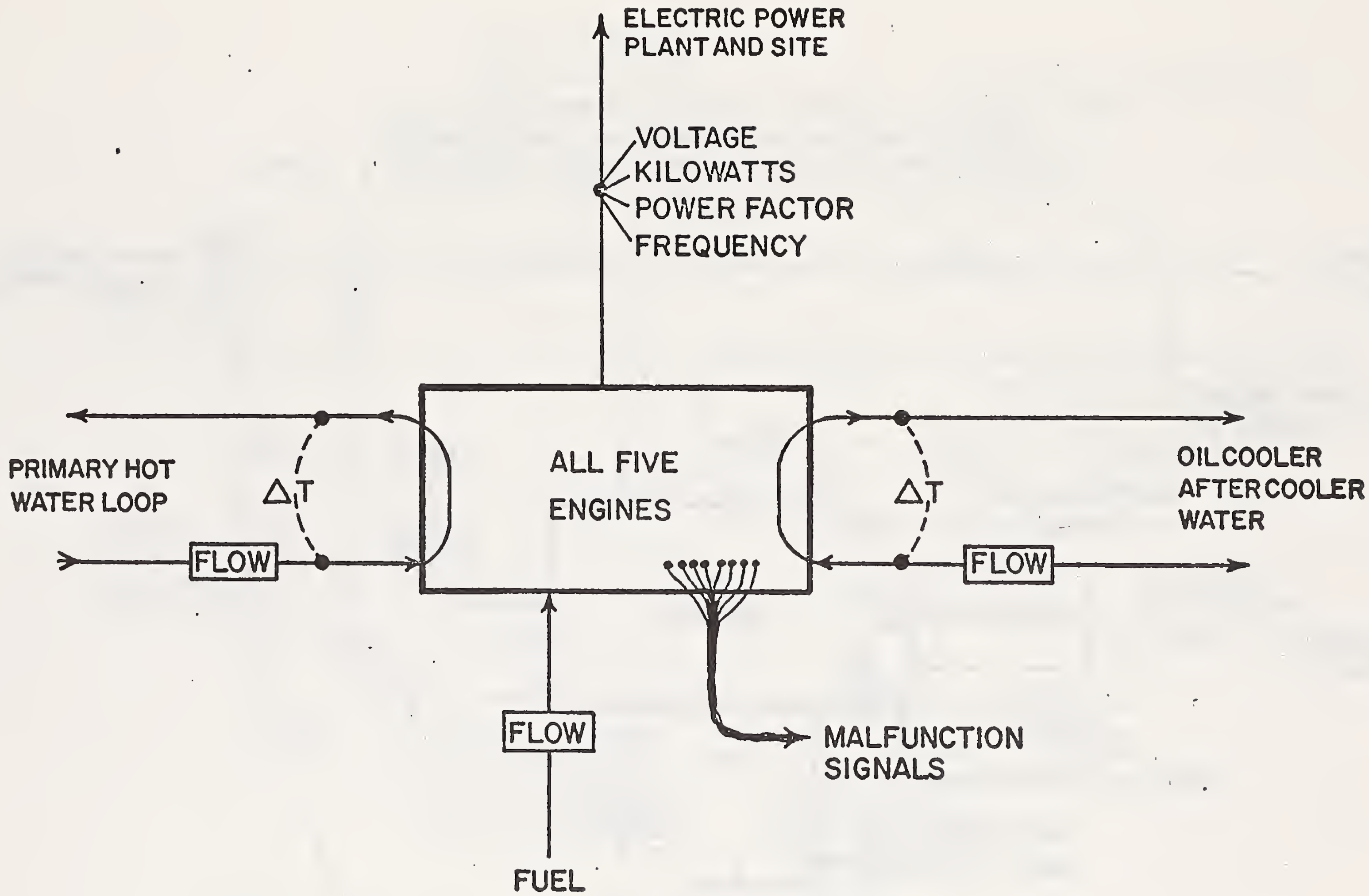

Figure 7 Schematic of the Instrumentation Monitoring the "Group" performance of all five engine-generators.

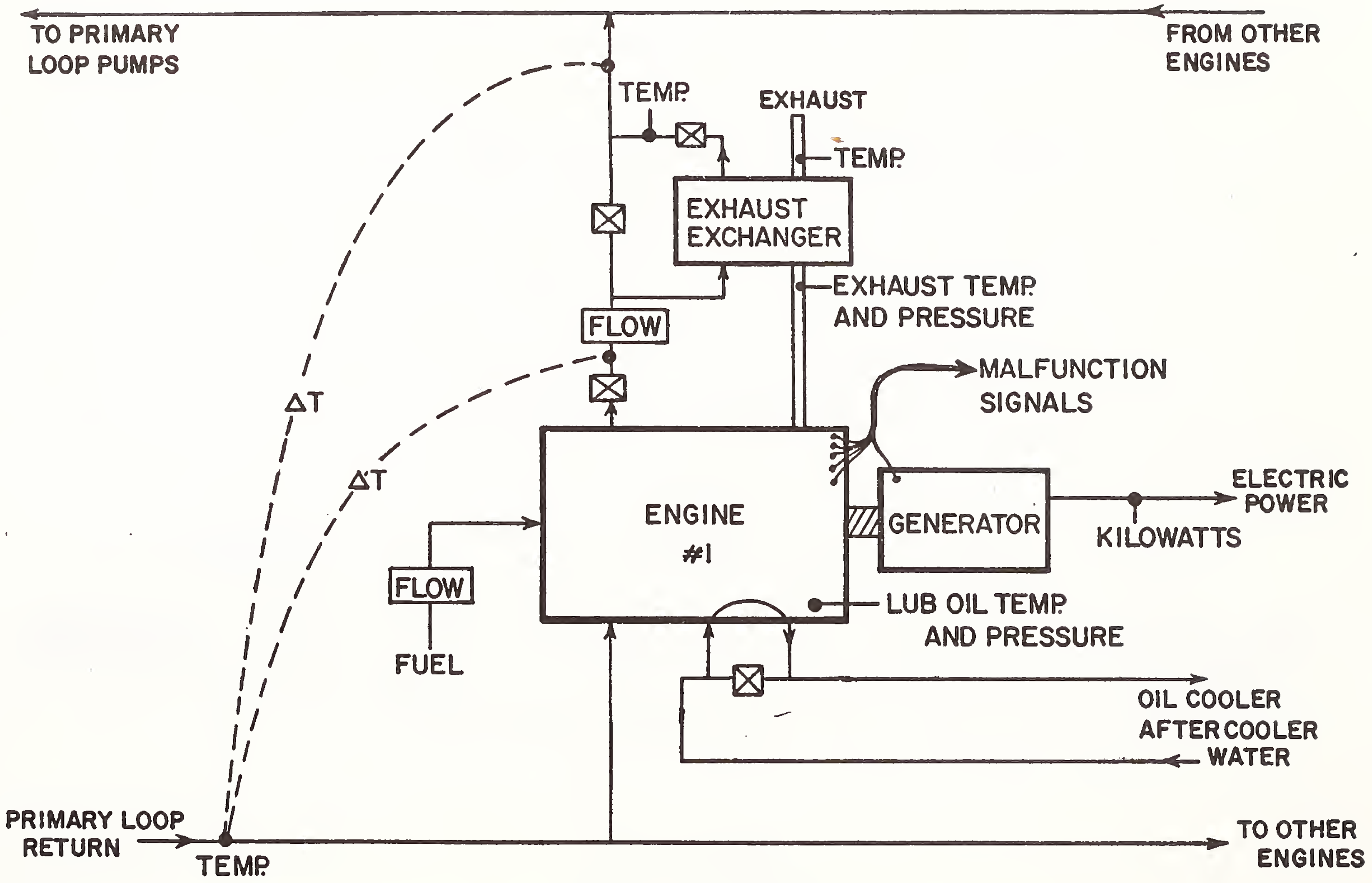

Figure 8 Schematic of the instrumentation monitoring the "individual" performance of engine-generator 1. Instrumentation on engine-generator 2 is the same.

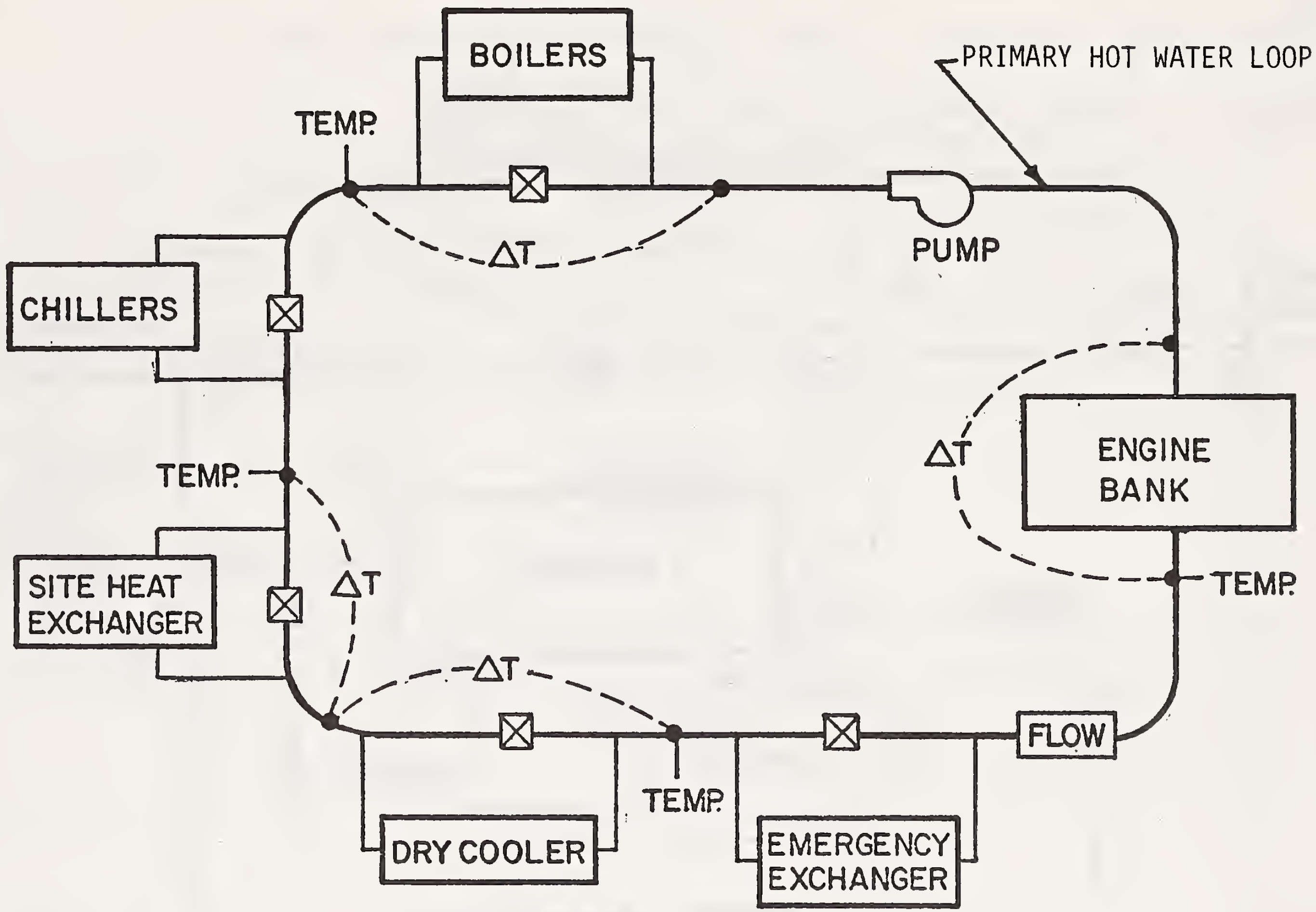

Figure 9 Schematic of the instrumentation monitoring the energy flow into and out of the primary hot-water loop.

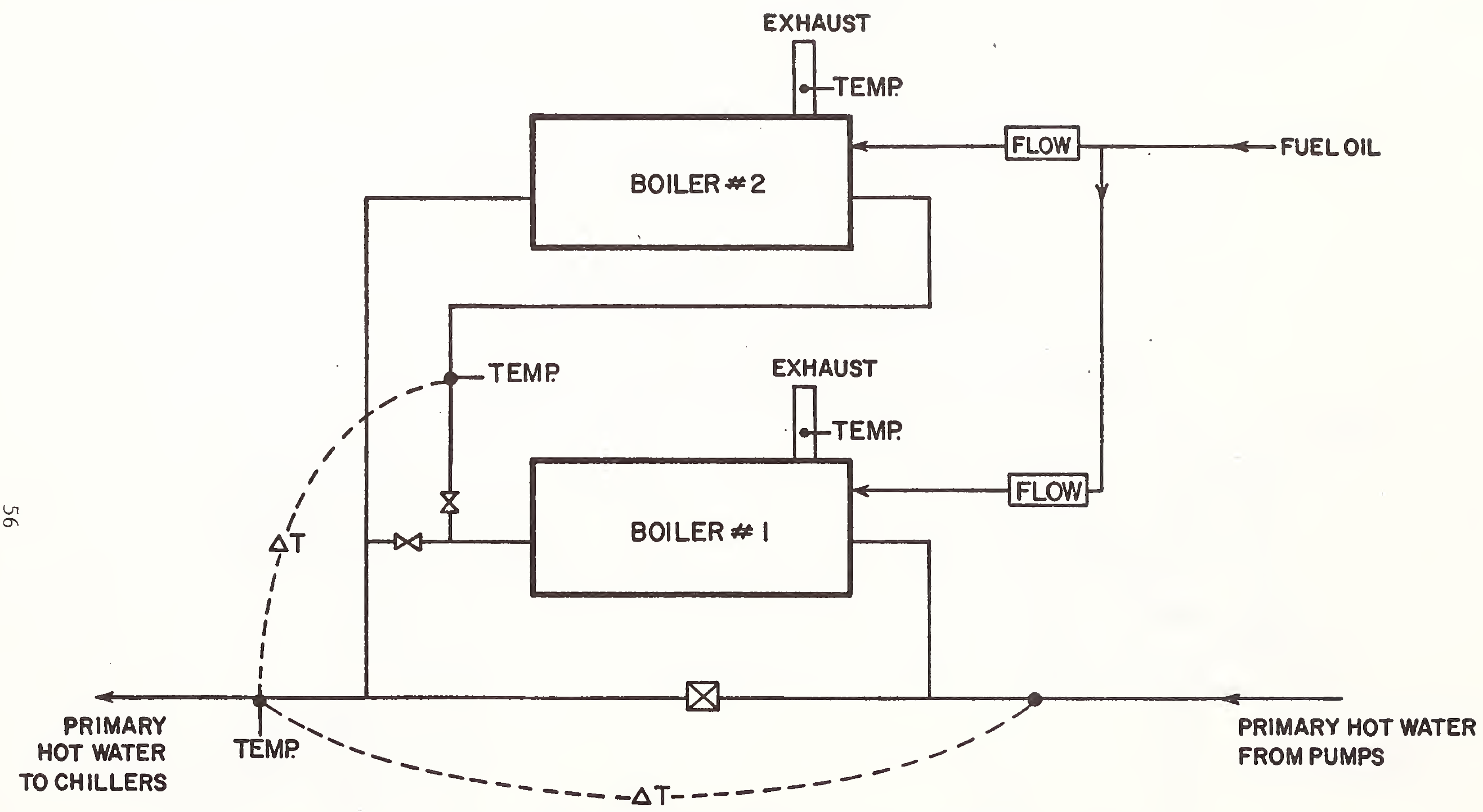

Figure 10 Schematic of primary water flow through boilers. Valves are provided to select primary water flow through both boilers in series or through a single boiler.

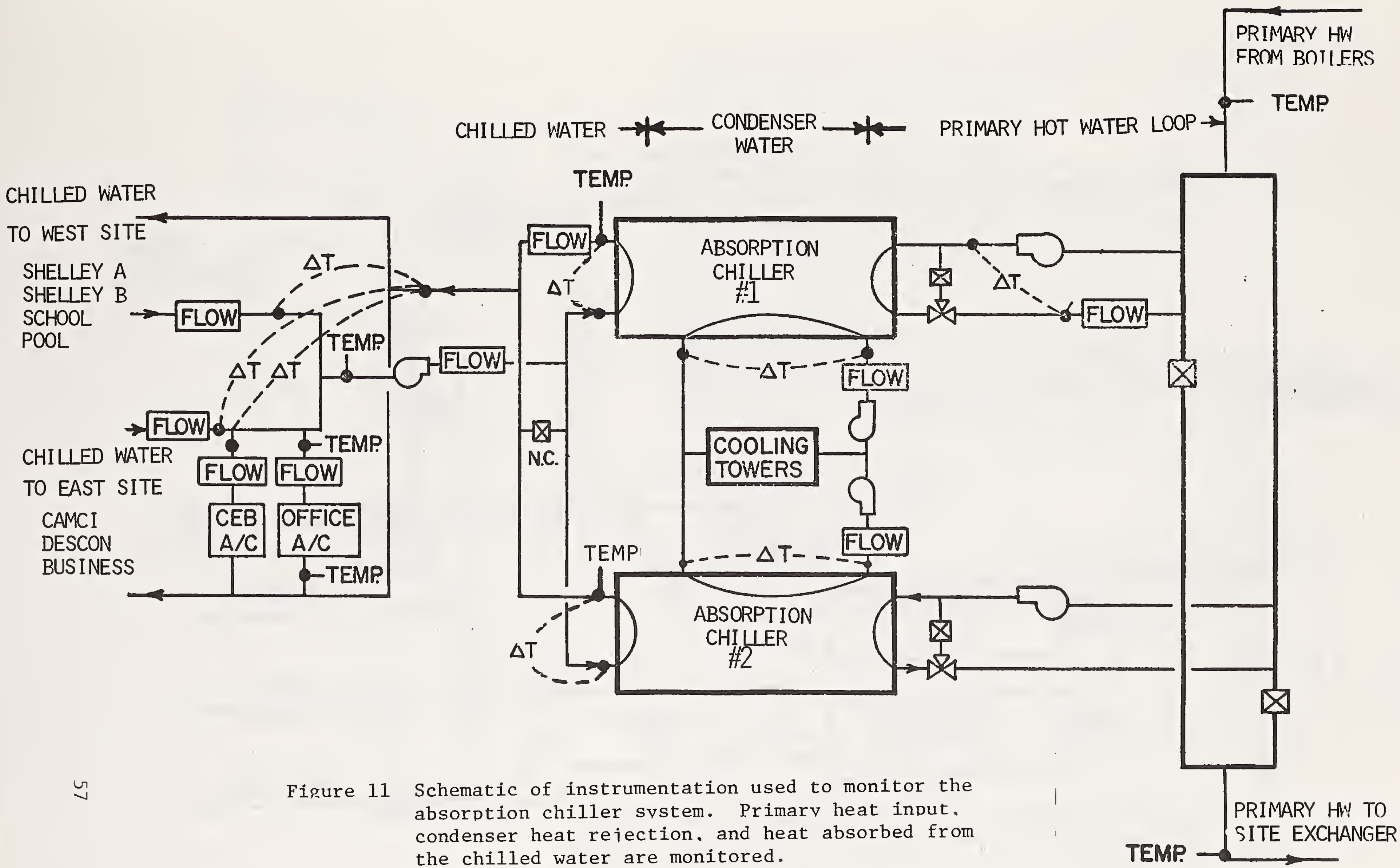

Figure 11 Schematic of instrumentation used to monitor the absorption chiller system. Primary heat input, condenser heat rejection, and heat absorbed from the chilled water are monitored.

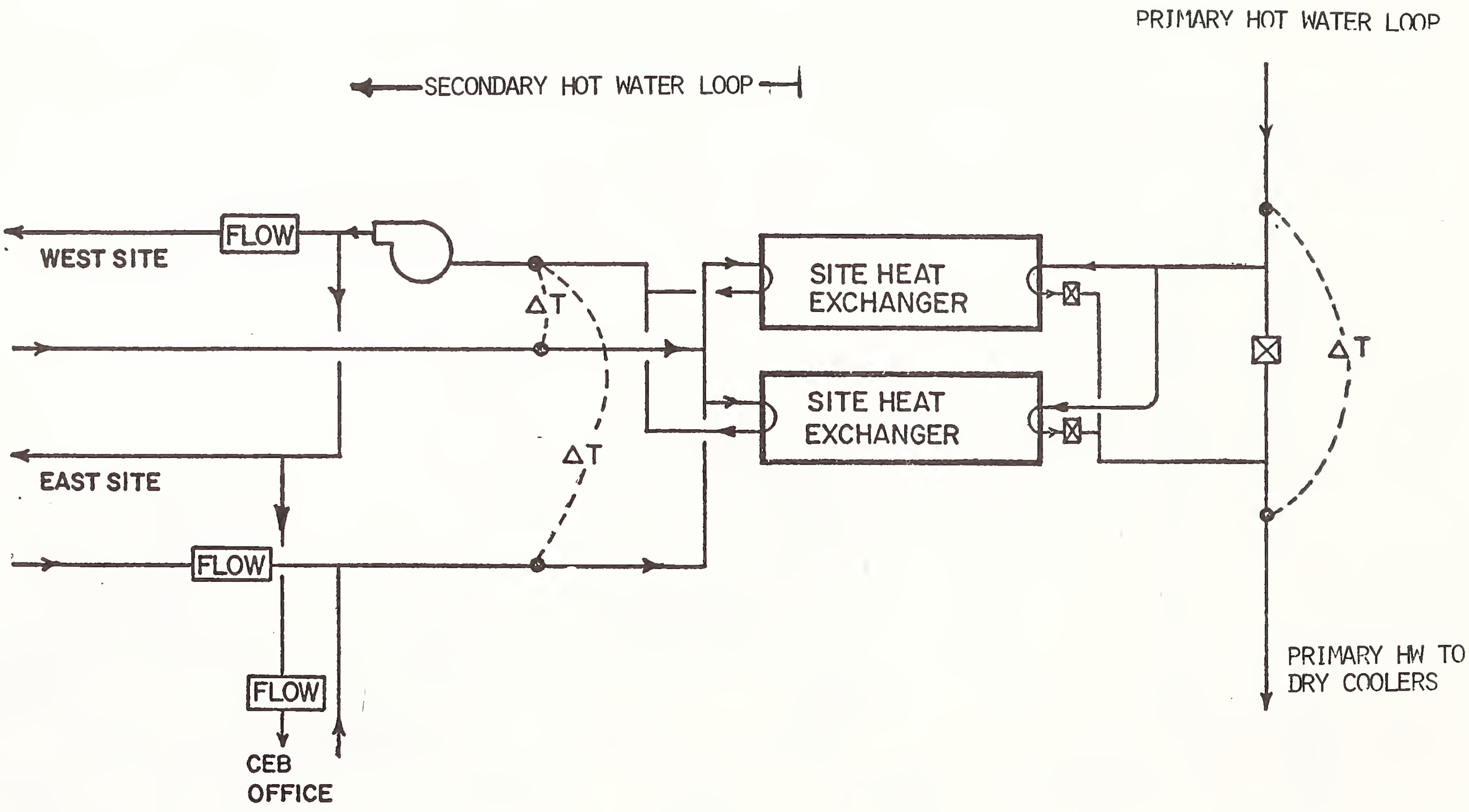

Figure 12 Schematic of instrumentation monitoring primary and secondary heat flow in and out of the site hot water heat exchangers.

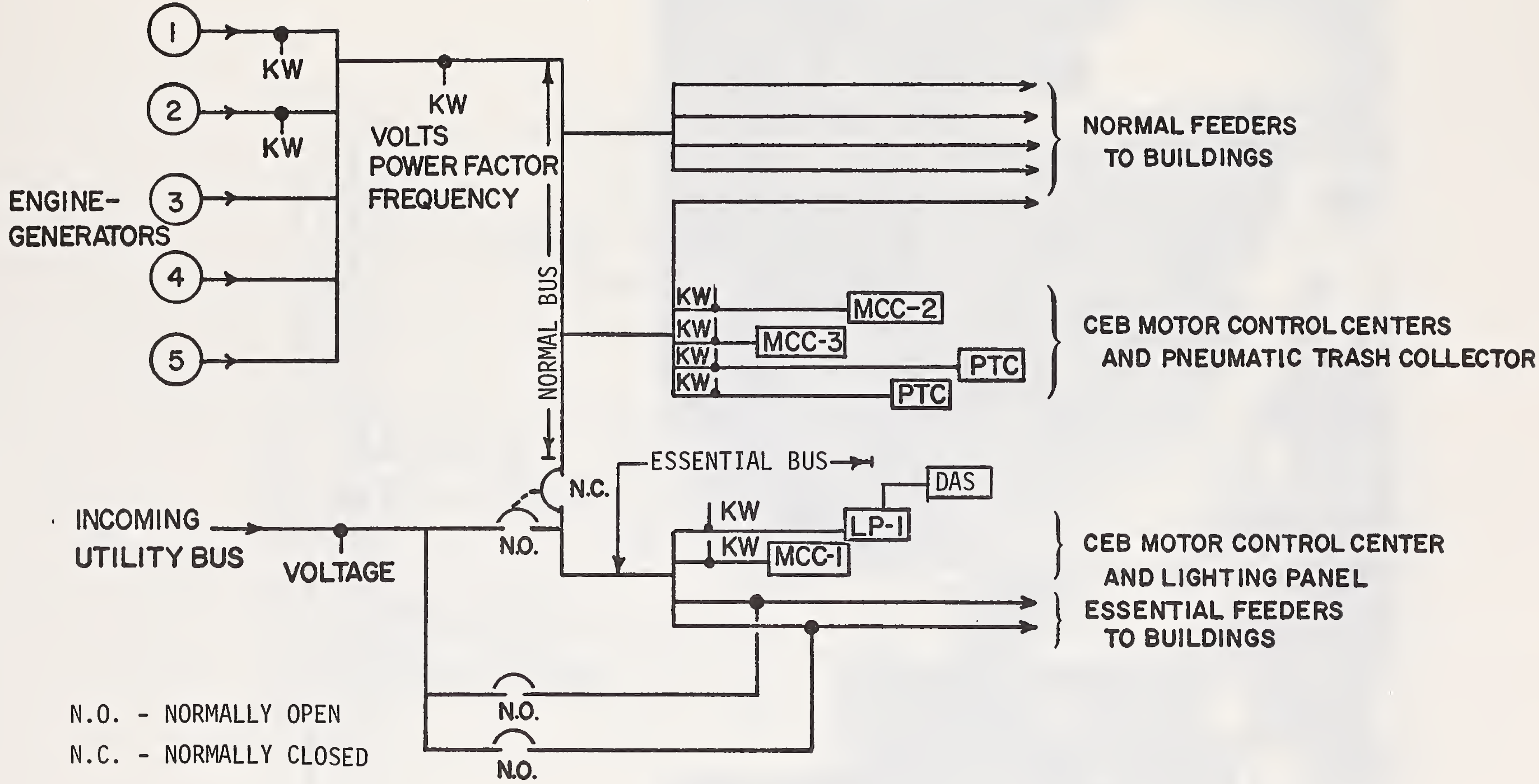

Figure 13 Schematic of Instrumentation Used to Monitor Electrical Energy Flows in the Plant. Diagrams of Normal and Essential Feeders to Individual Buildings Shown in Appendix.

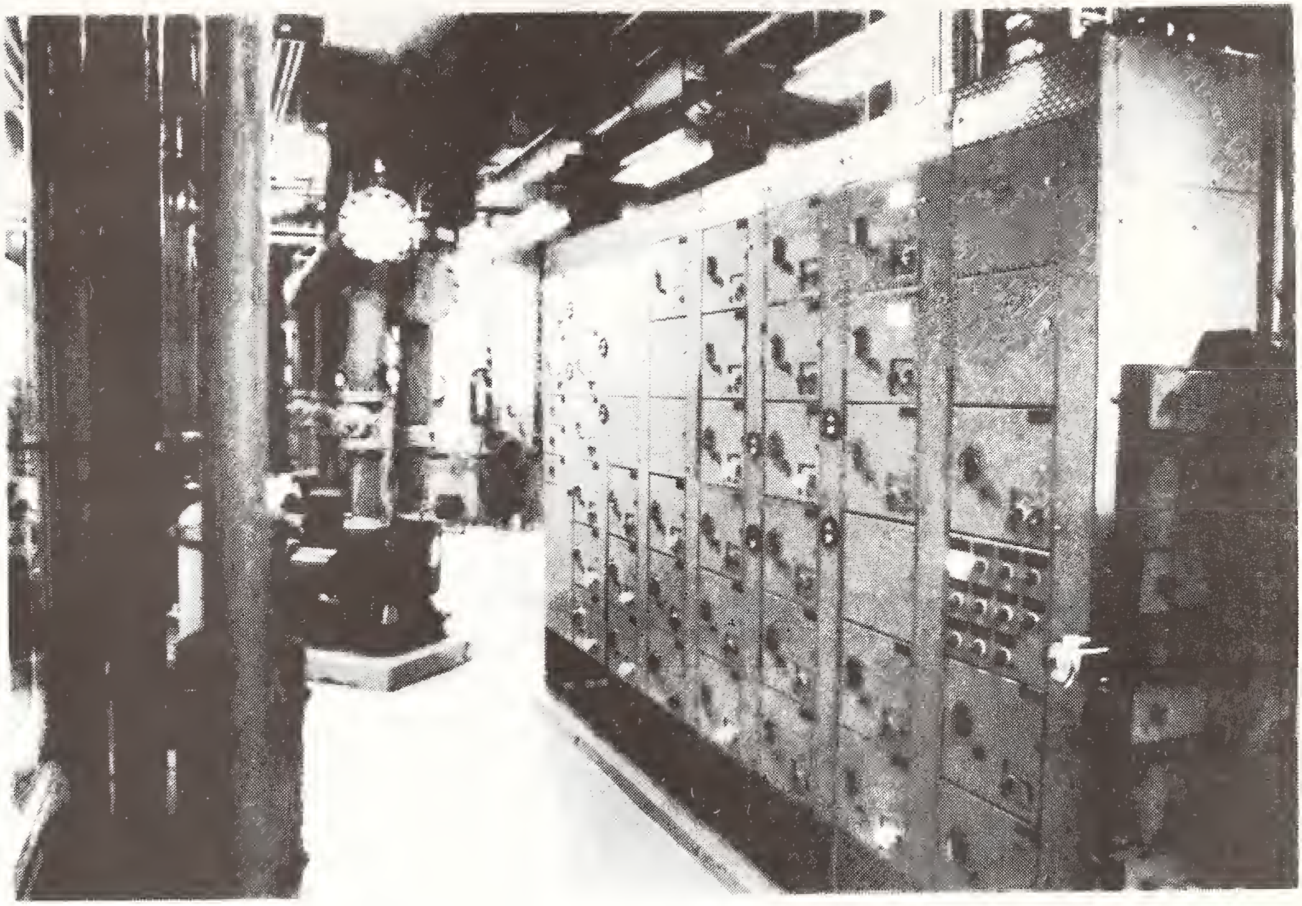

Figure 14 MCC-1, one of three plant motor control centers. MCC-1 is located in the engine room and distributes power from the plant essential bus to equipment necessary to support engine operation. The primary hot water pumps are are visible in the background.

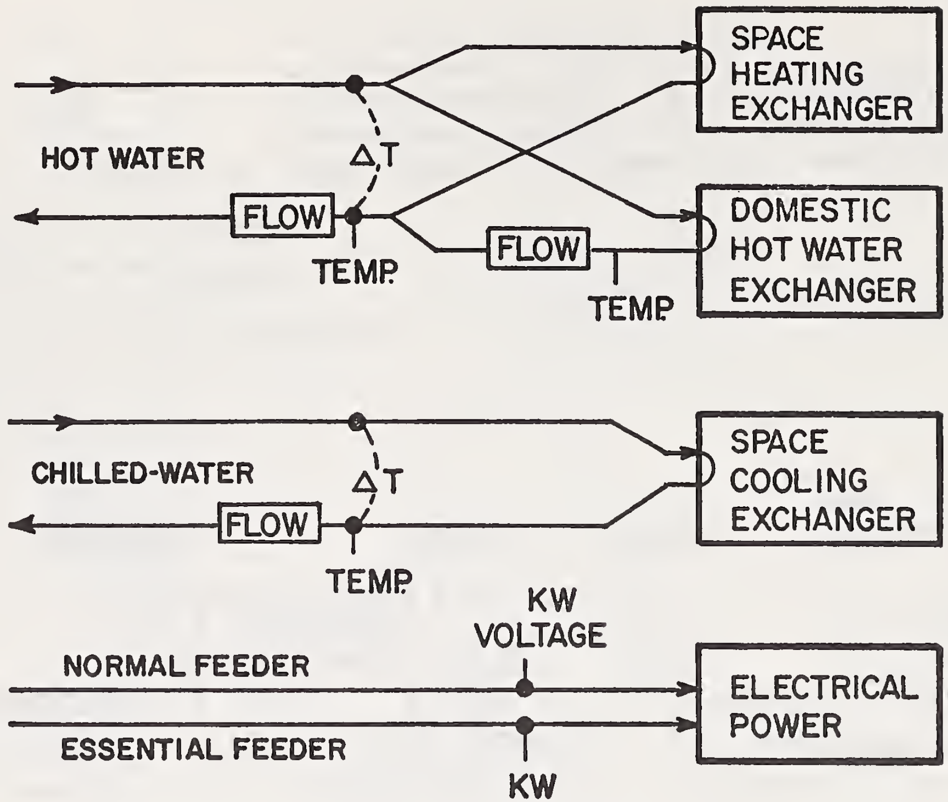

Figure 15 Typical Schematic of Instrumentation Used to Monitor an Individual Building's Demands. Some Buildings may have Different Instrumentation Arrangements because their Mechanical and Electrical Contractors Chose Different Designs.

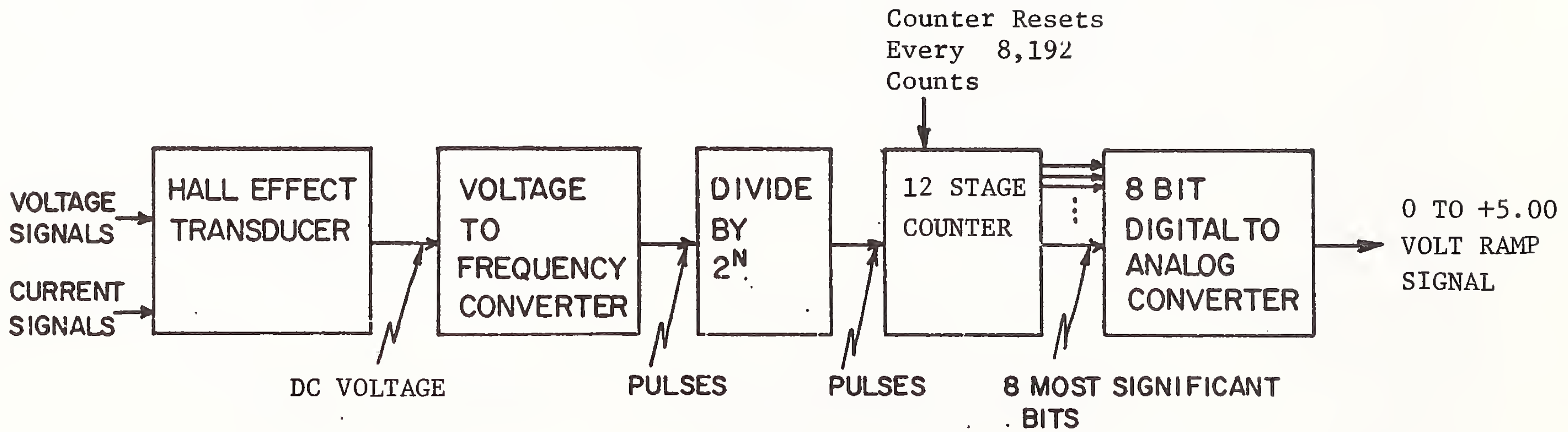

Figure 16 Block Diagram of Kilowatt-Hour Integration Scheme. Voltage and Current Signals come from Potential and Current Transformers. N in the Divide Circuit is set by Thumbwheel. Figure 17 illustrates use of this system in a three phase power feeder.

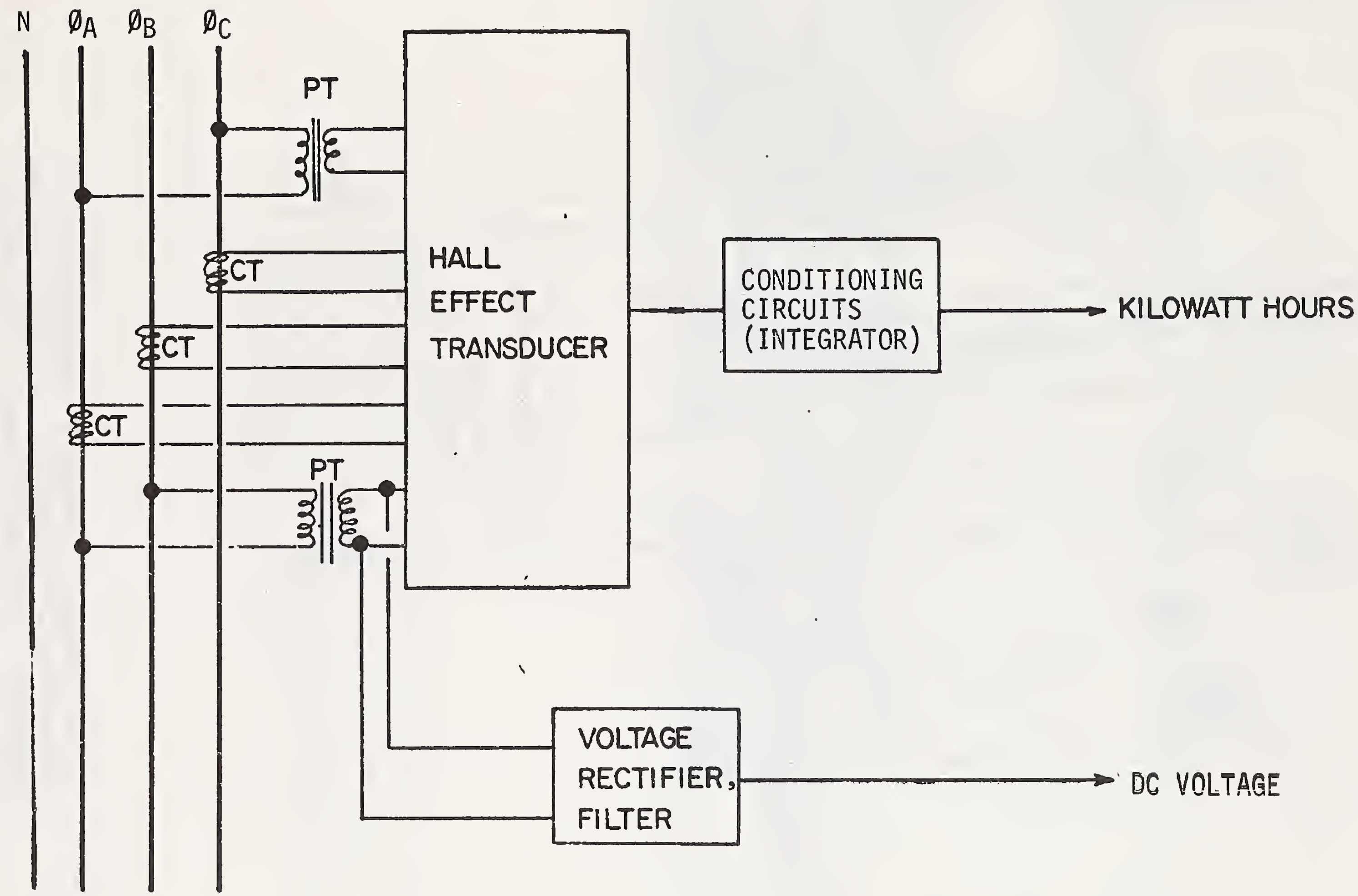

Figure 17 Diagram of power and voltage measurements on the CEB main power bus.

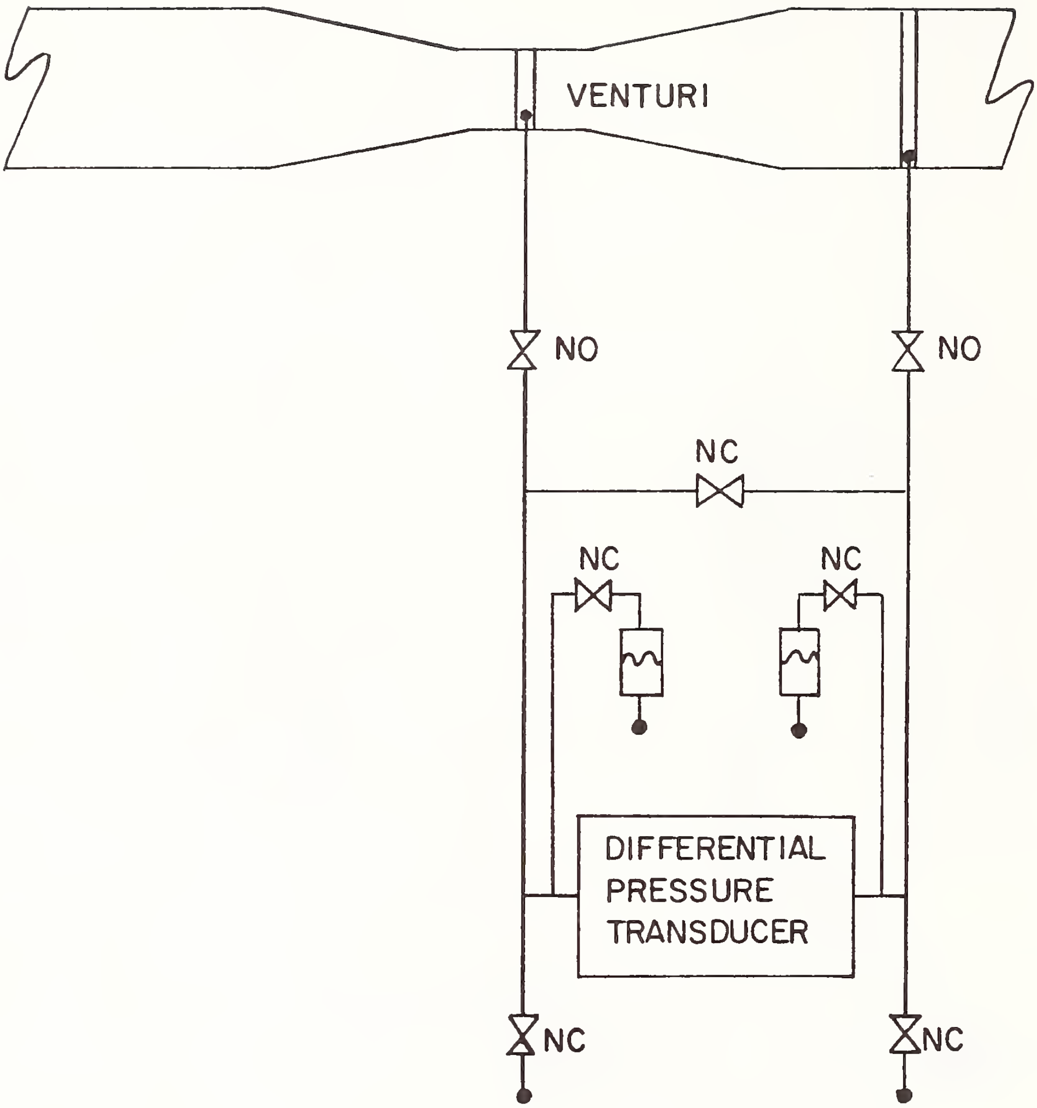

Figure 18 Piping diagram of venturi, differential pressure cell, bleed ports, and calibration diaphrams. Figure 19 shows a photo of a typical unit.

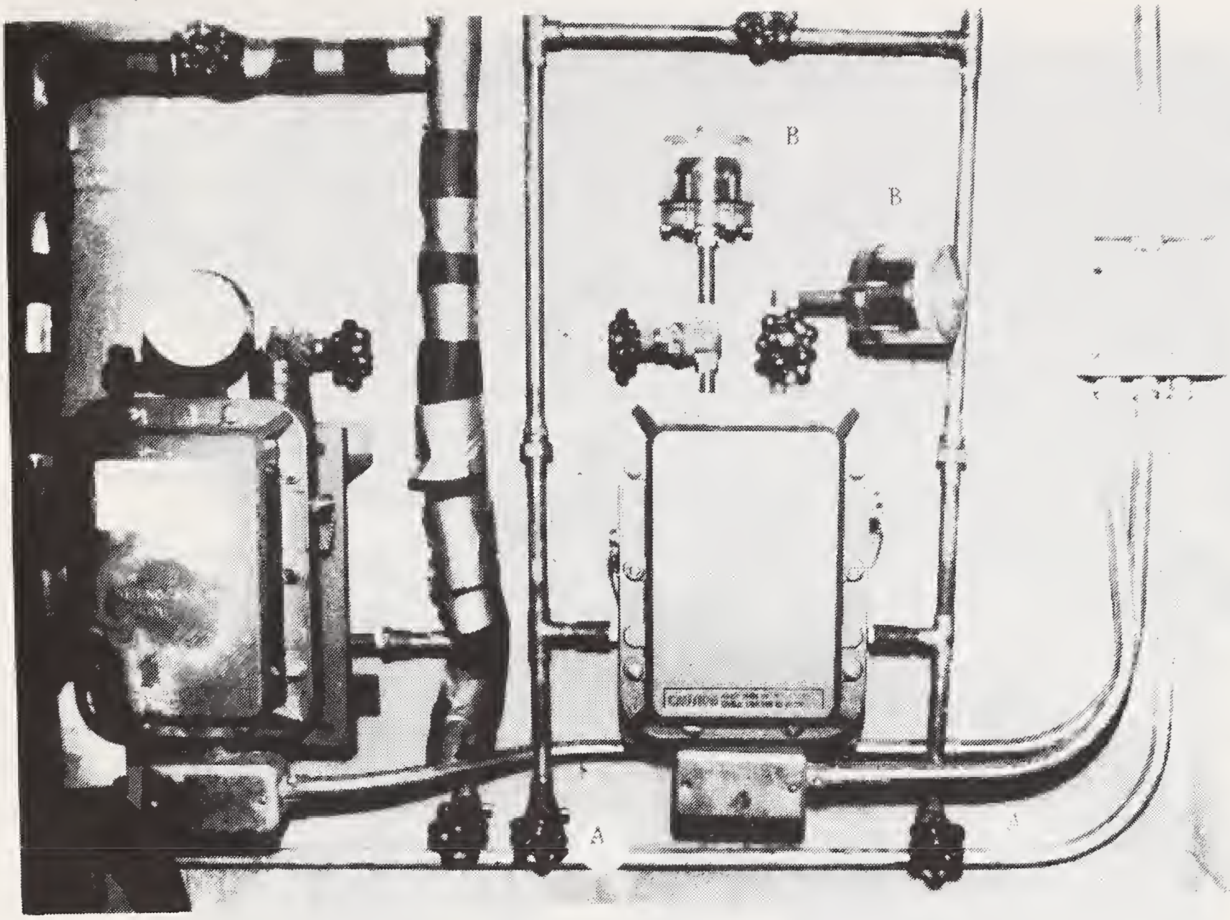

Figure 19 Typical hookup of differential pressure cell used with venturi to measure flow rates. The venturi is located above this apparatus as shown in the Figure 18 diagram. Note the two bleed valves (A) at the bottom of the photograph and the two calibration interfaces (B) just above the pressure cell box.

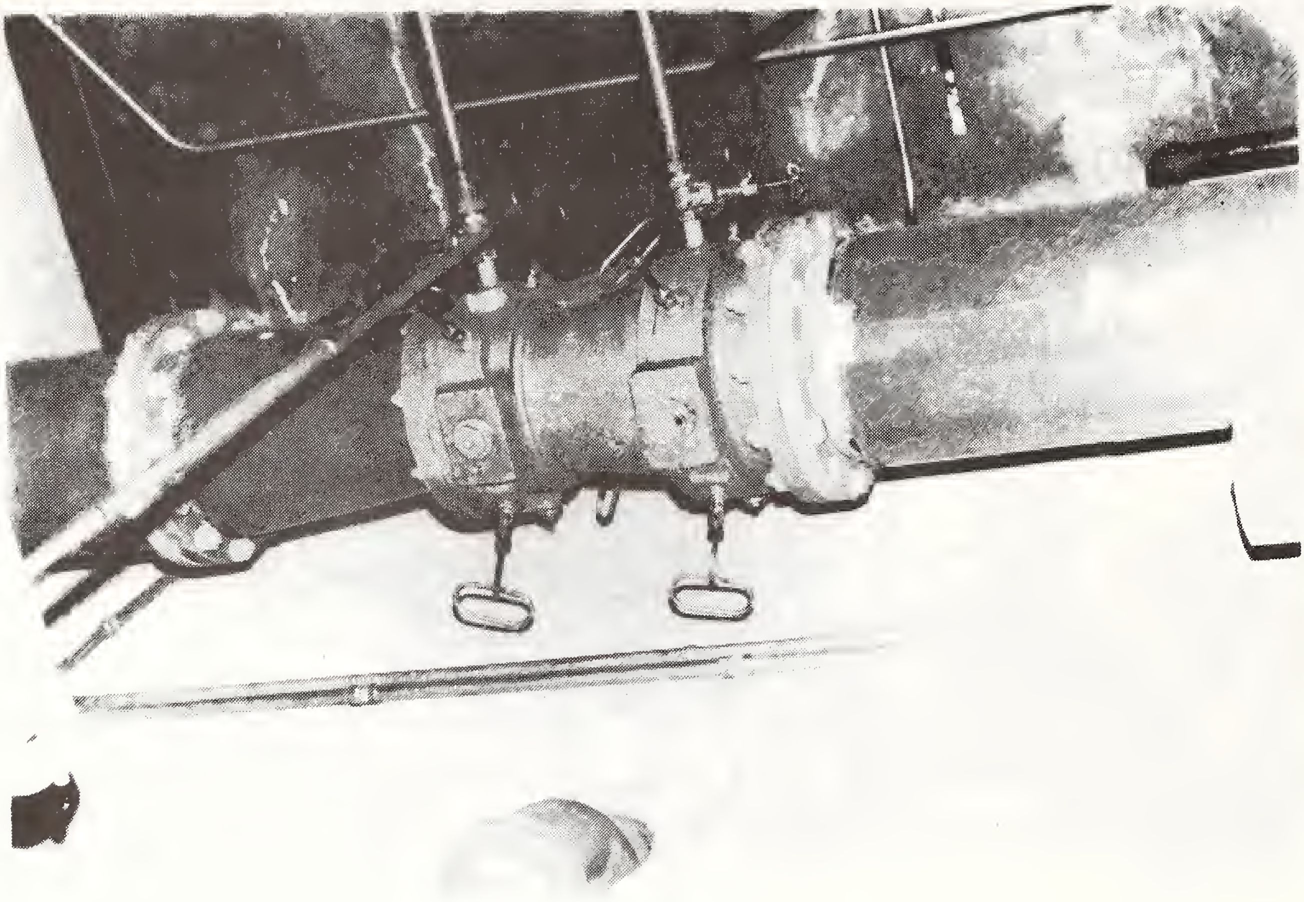

Figure 20 Venturi installed in 10 inch pipe. Downstream portion of the venturi is covered with pipe insulation.

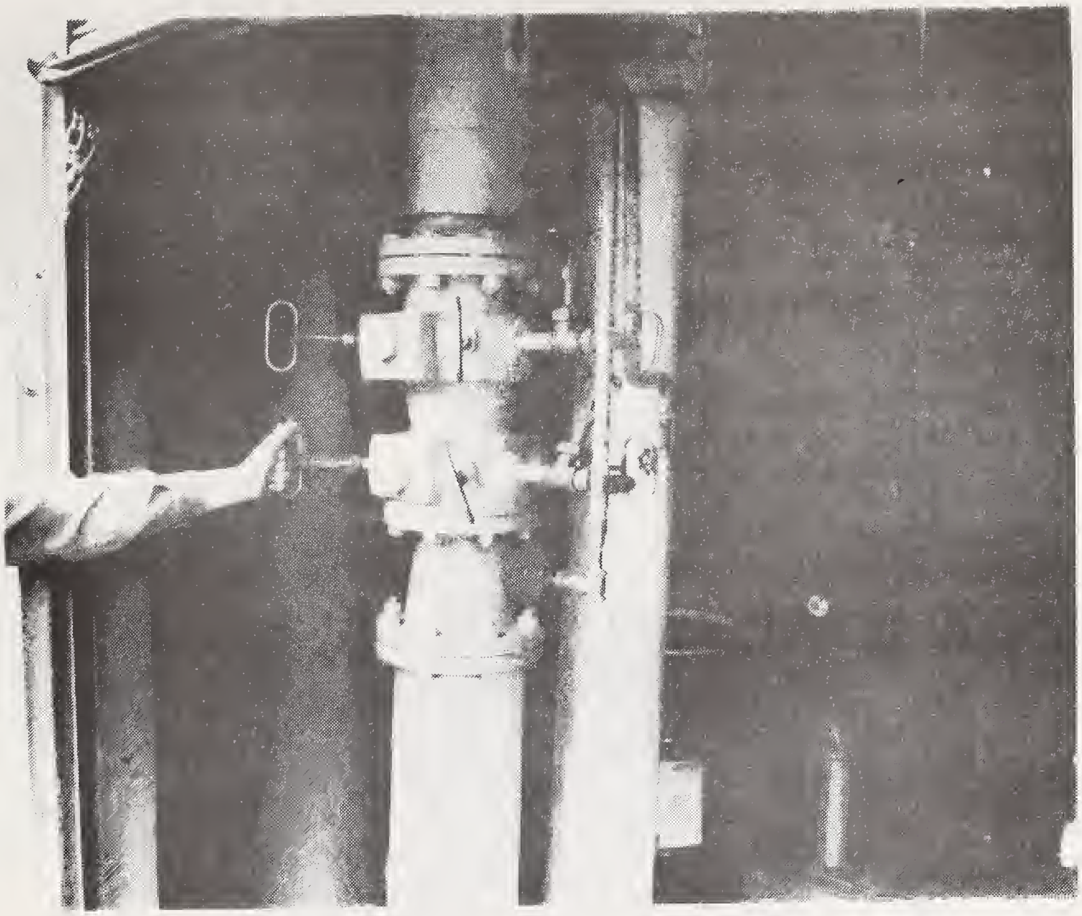

Figure 21 Venturi cleanout operation. Rod is pushed in and then returned to clear sediment from the venturi's two annular pressure pick-off rings.

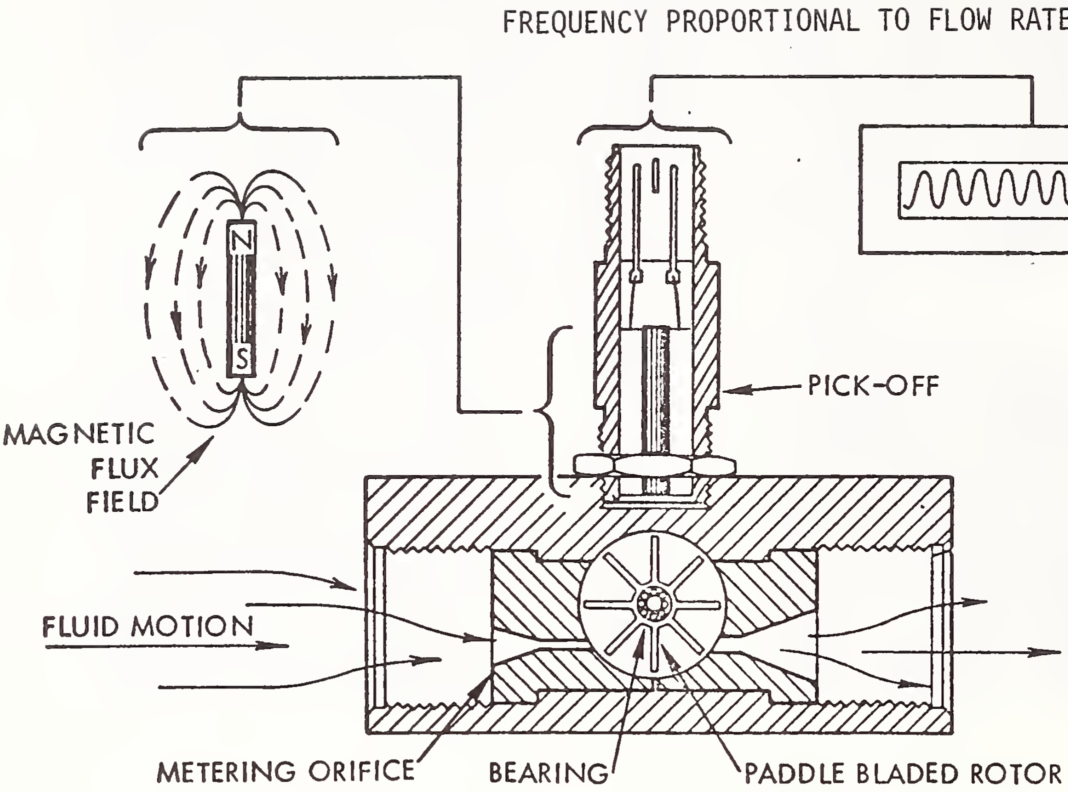

Figure 22 Diagram of the Omniflo turbine flowmeter with a typical output signal.

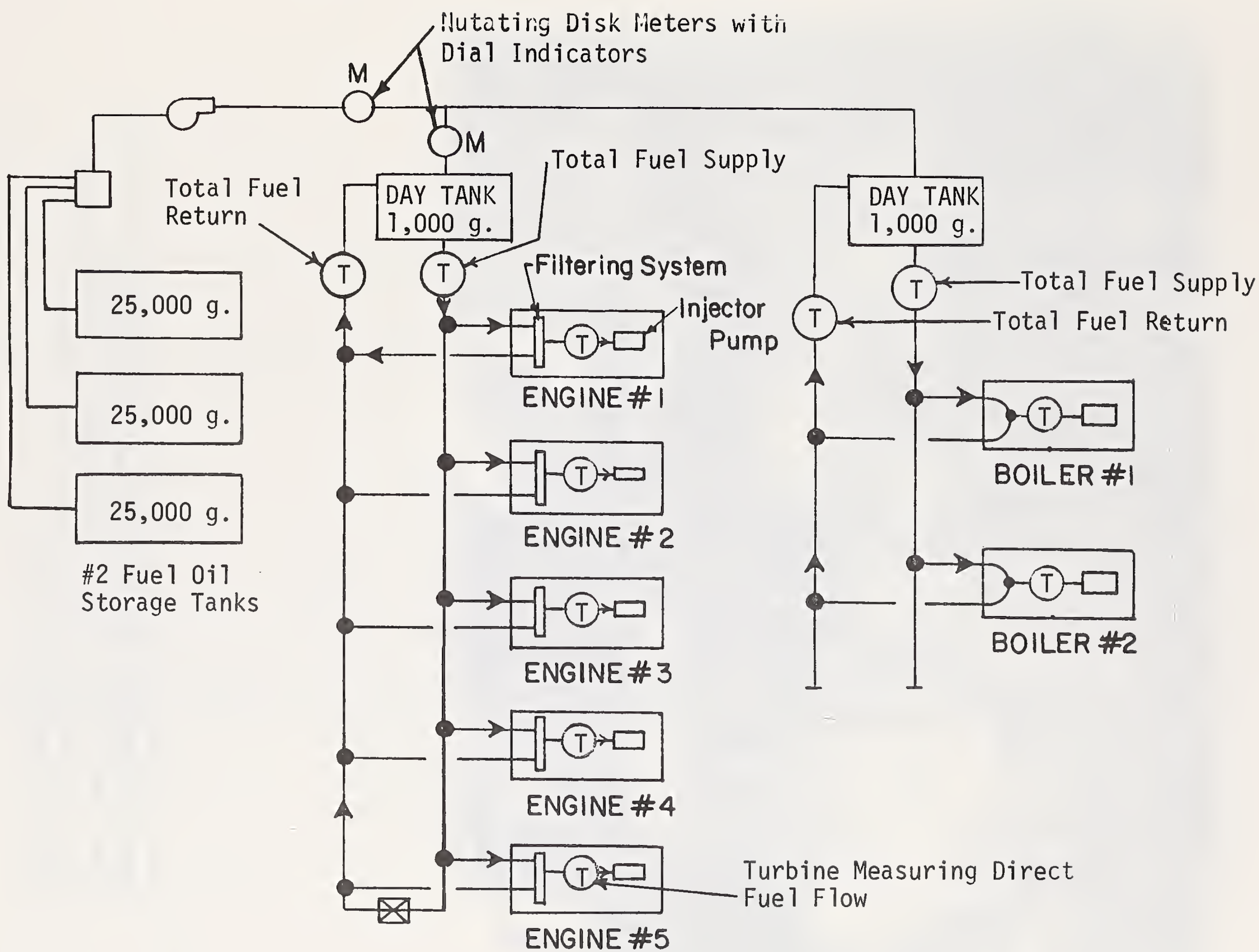

Figure 23 Diagram showing major elements of fuel measurement system. Nutating disk flowmeters (M),

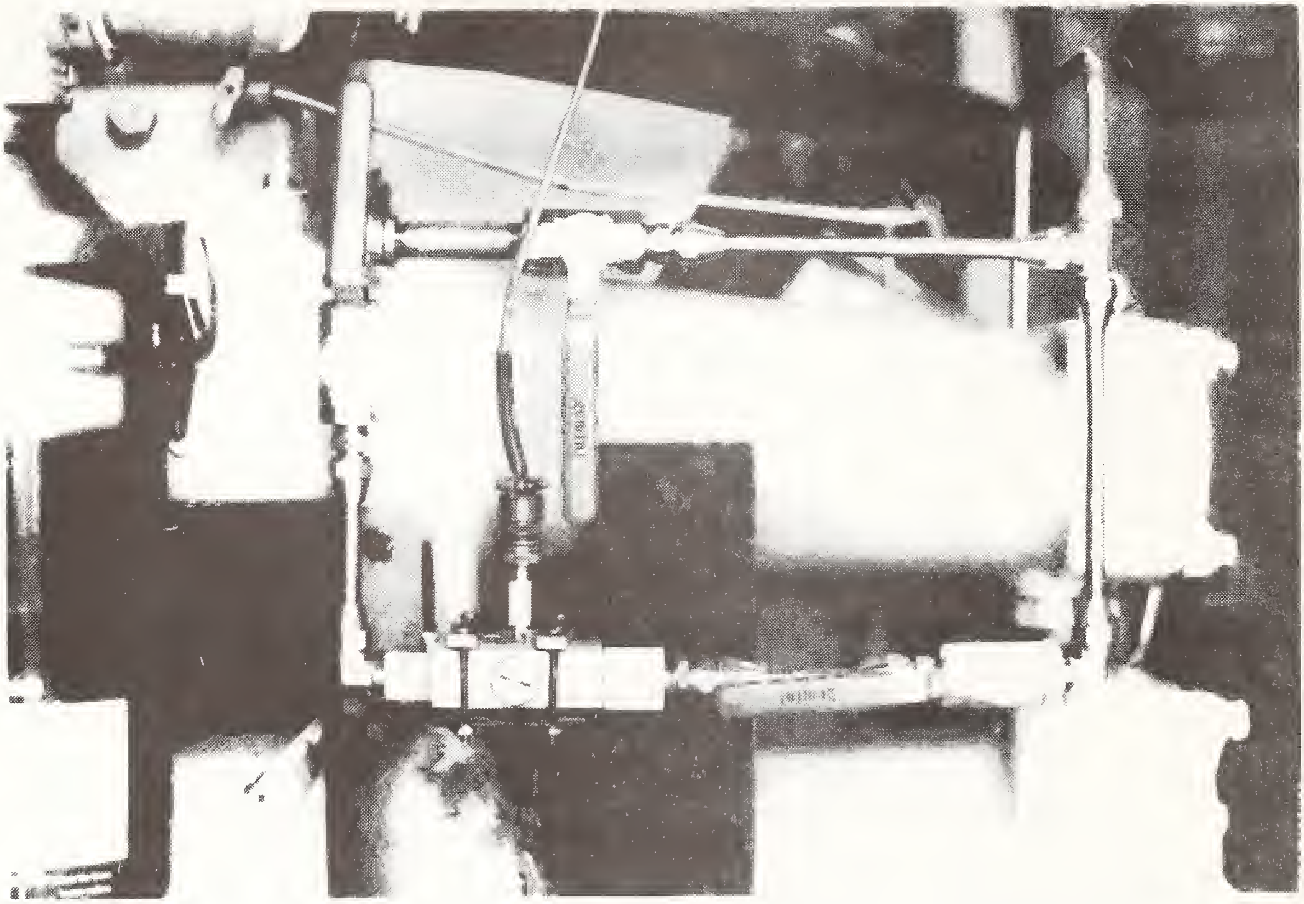

Figure 24 Fuel flowmeter installed on an engine. Flowmeter is installed between final filter and injector rack. Three gate valves shown allow flowmeter to be bypassed and isolated from line for servicing, without disrupted engine operation.

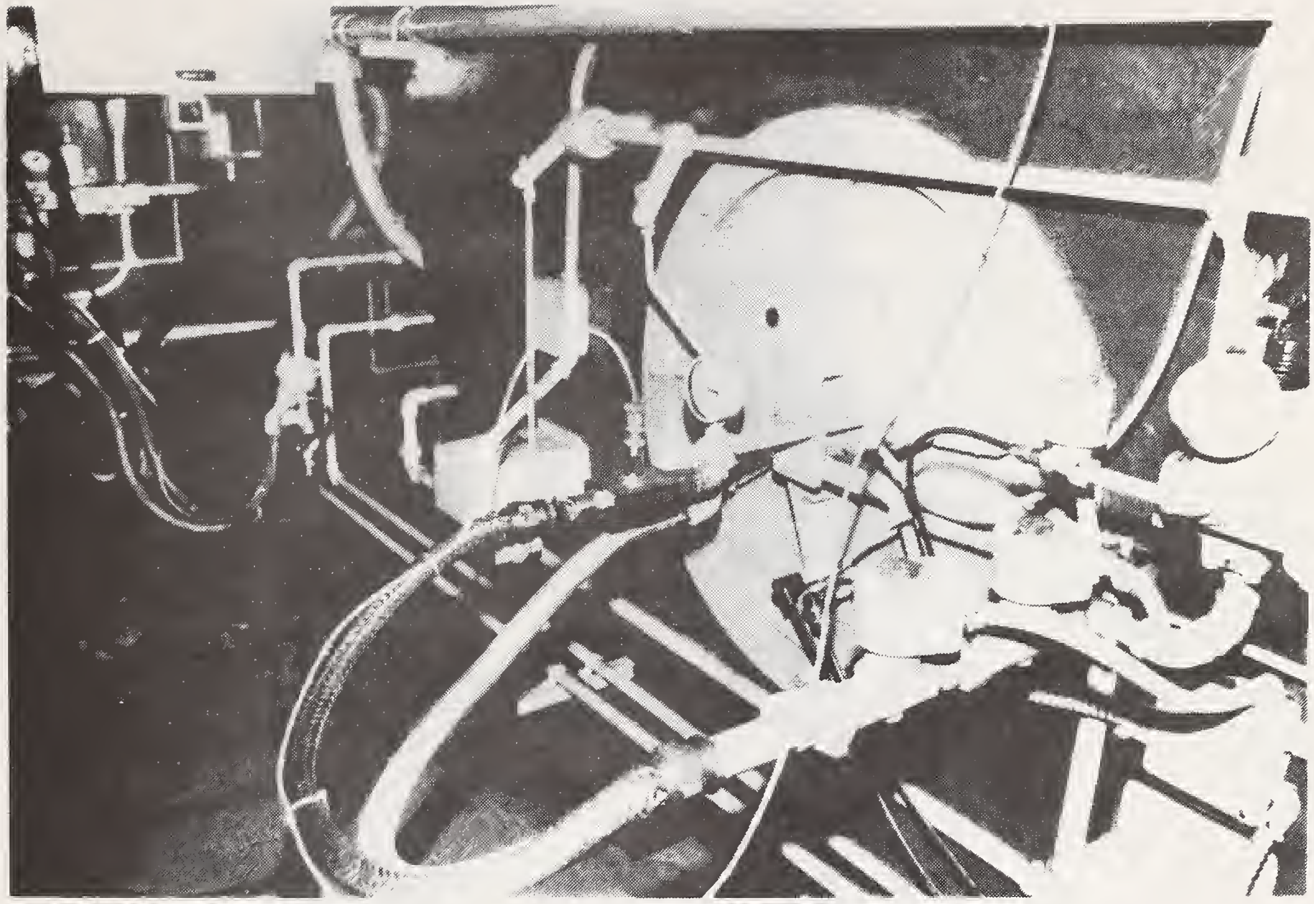

Figure 25 Fuel flowmeter installed on a boiler.

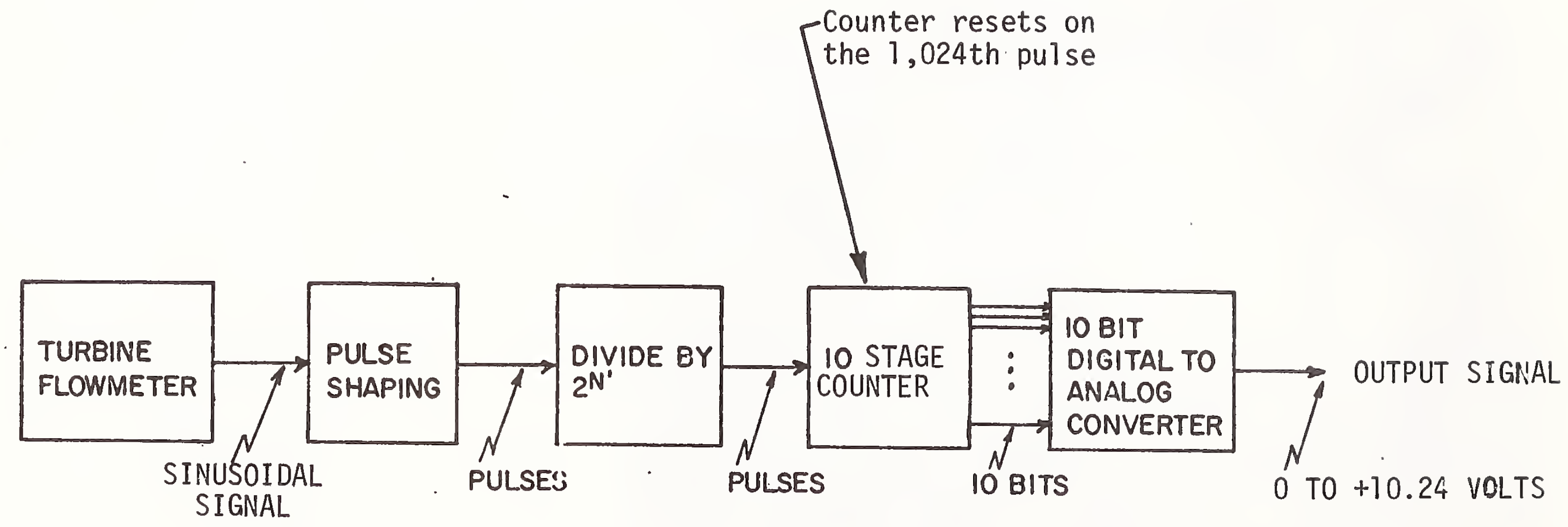

Figure 26 Block diagram of scheme used to integrate turbine signals. A thumbwheel switch is used to set N in the divider.

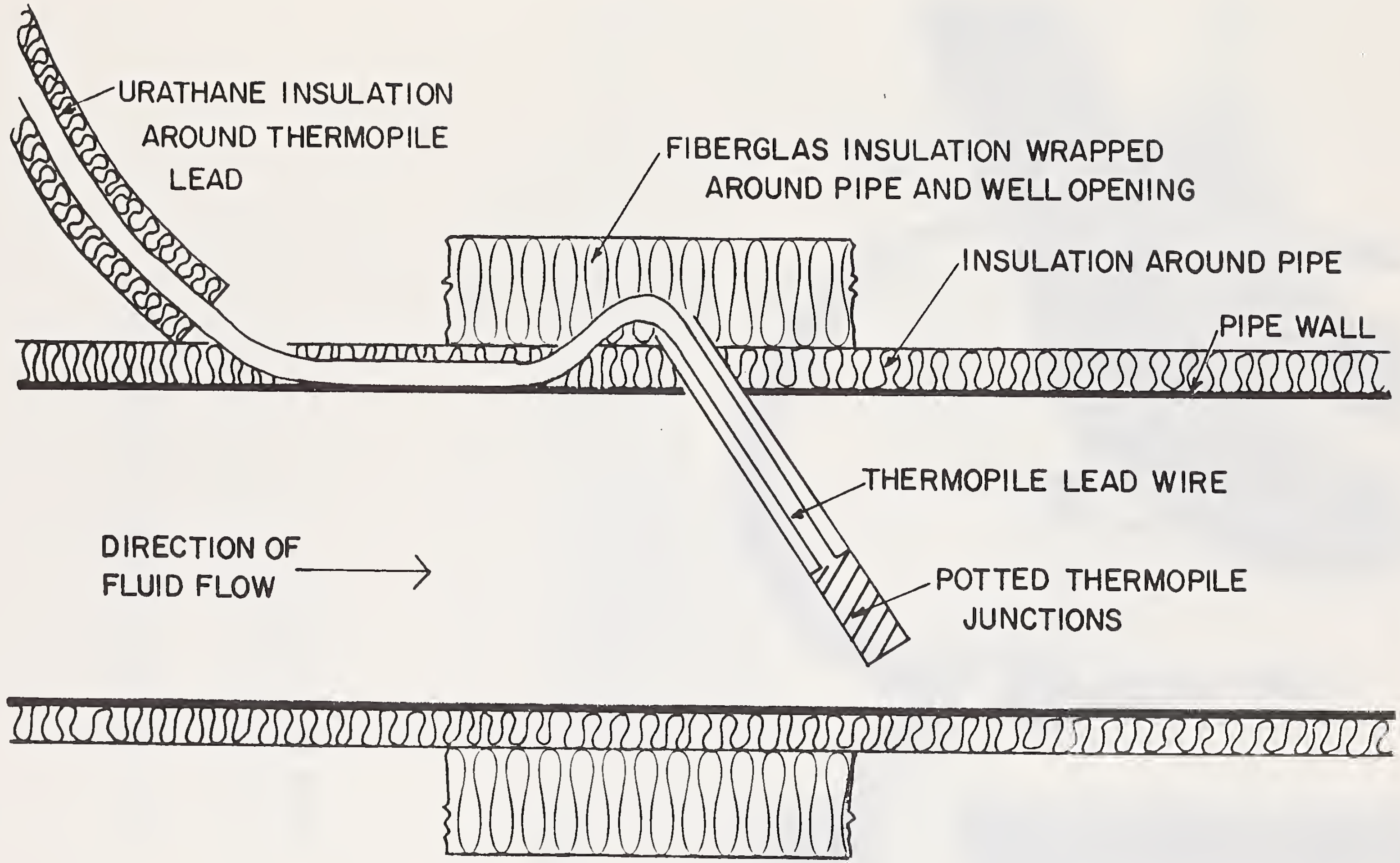

Figure 27 Diagram of typical thermopile in thermowell.

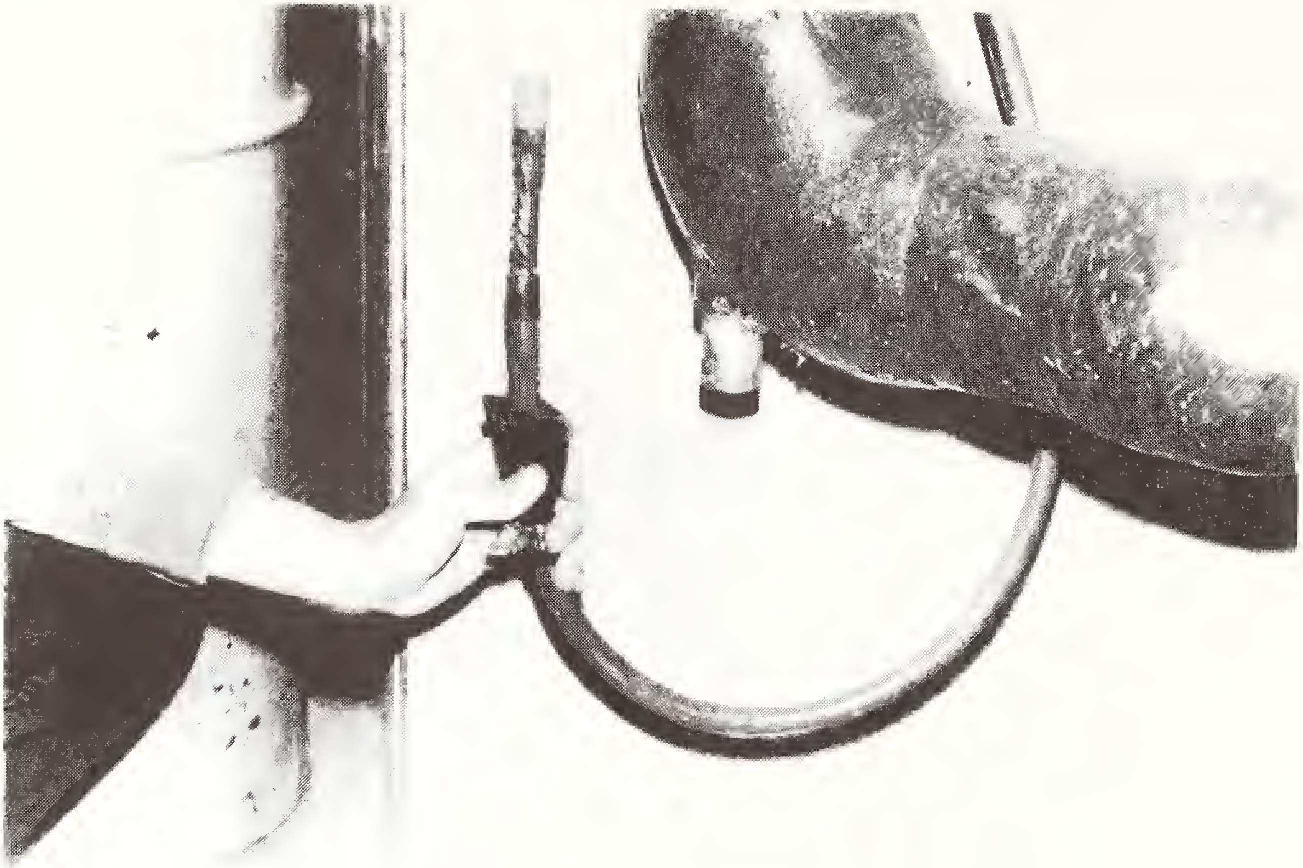

Figure 28 Example of thermopile

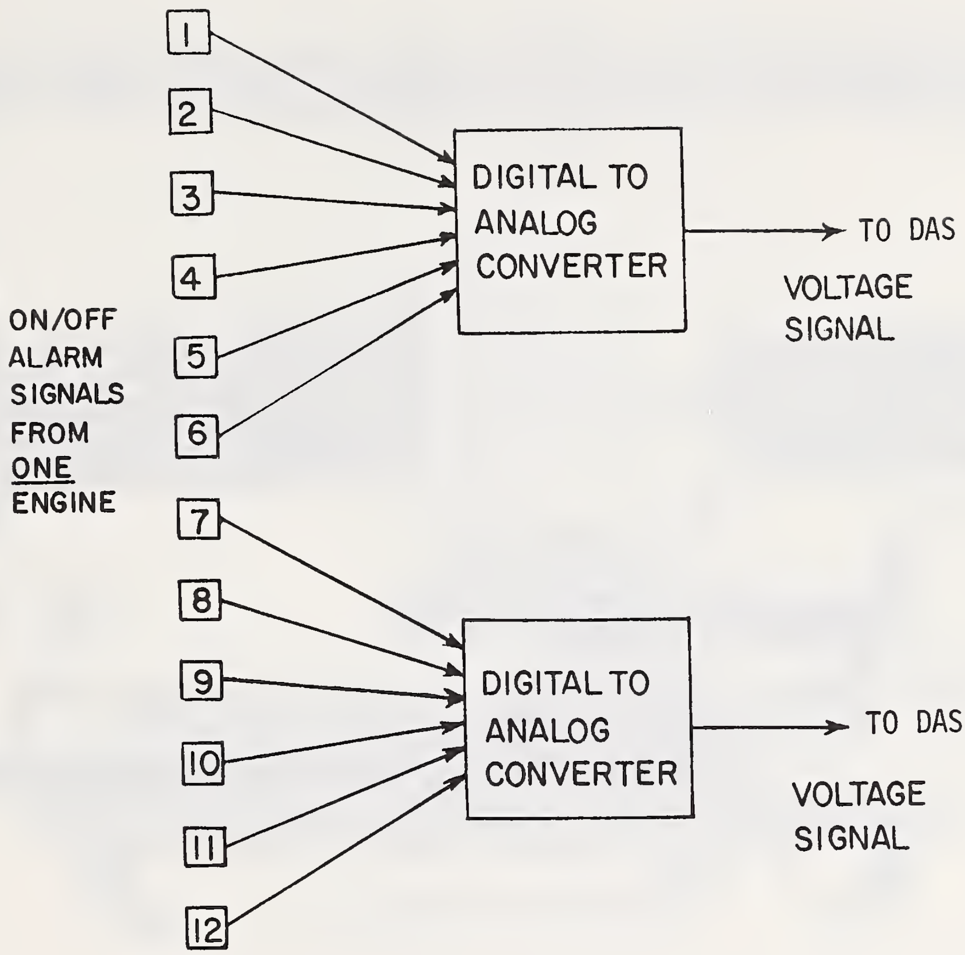

Figure 29 Block diagram of multiple engine alarms converted to a single signal line.

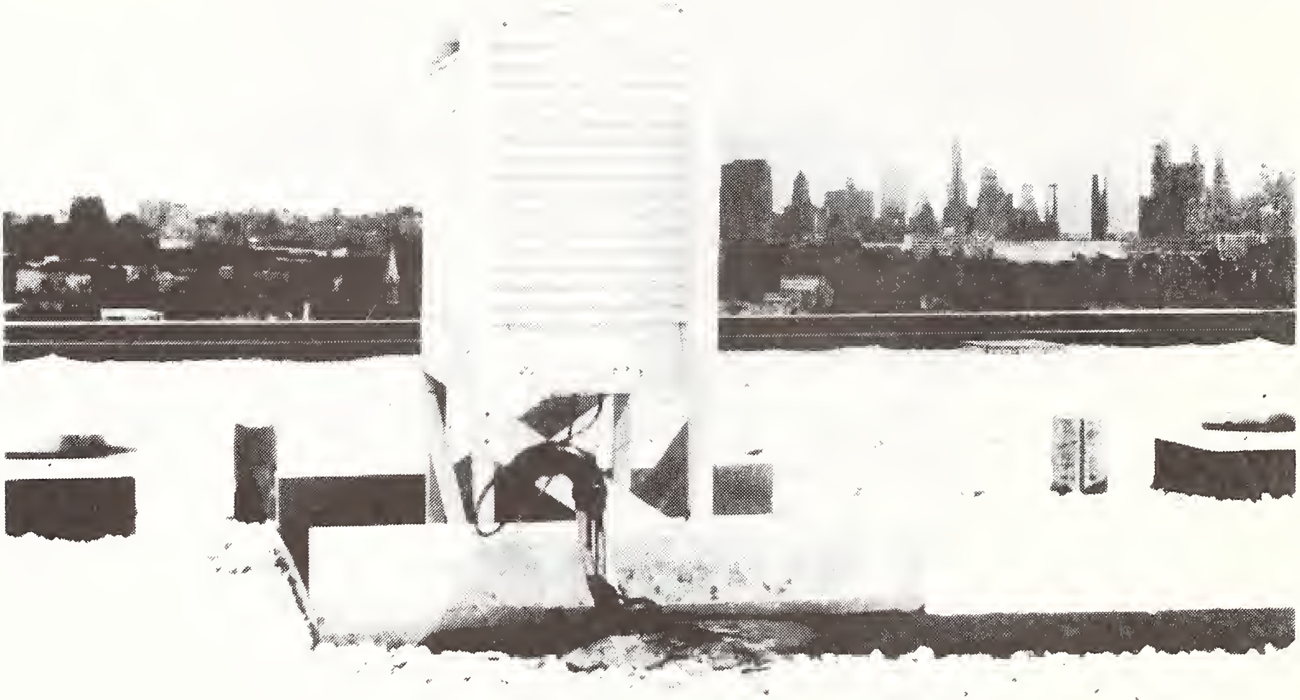

Figure 30 The shelter on the Descon-Concordia roof contains weather station transducers which measure temperature and relative humidity. Background is the New York City skyline.

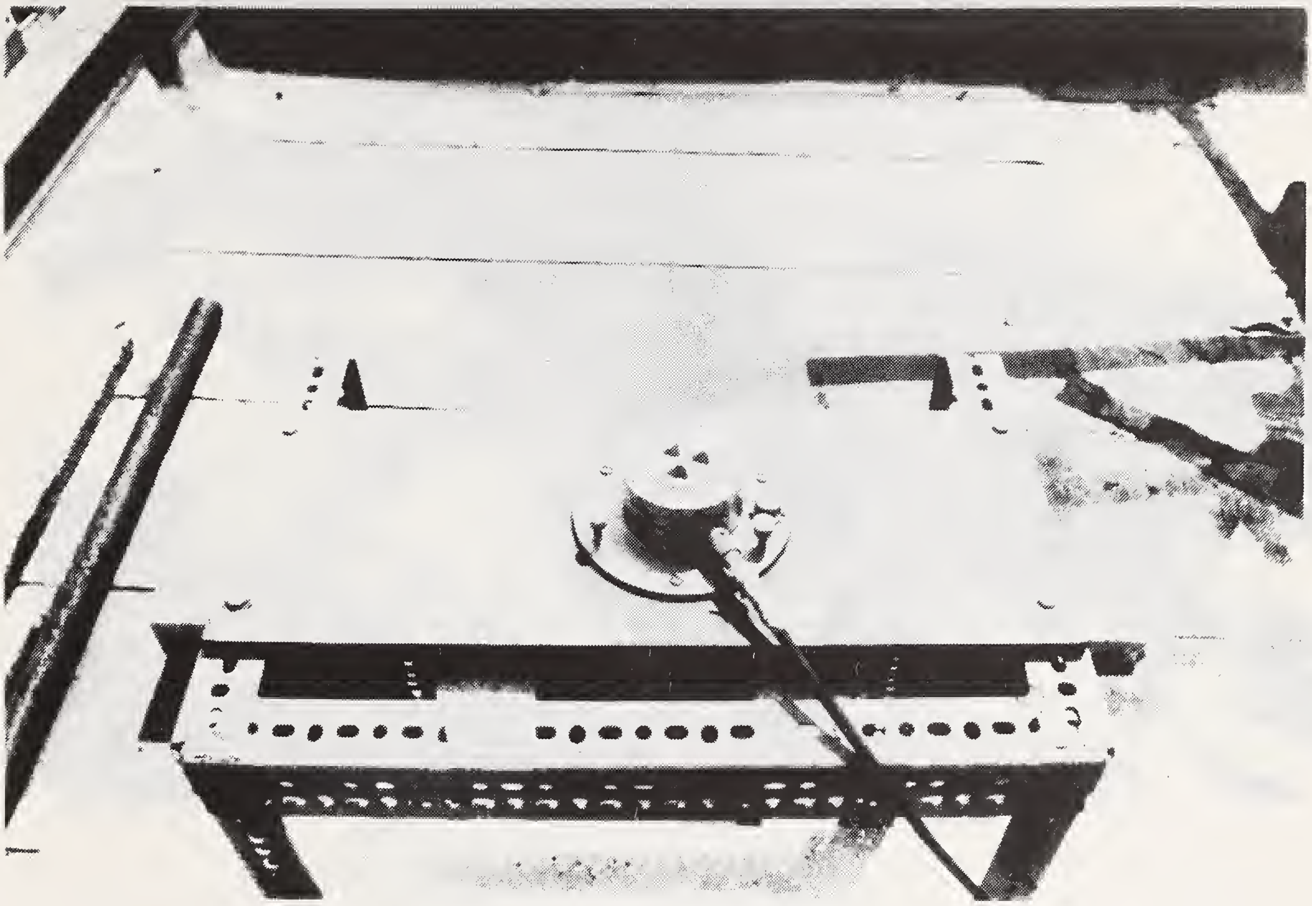

Figure 31 This pyranometer mounted on the Descon roof measures direct solar radiation.

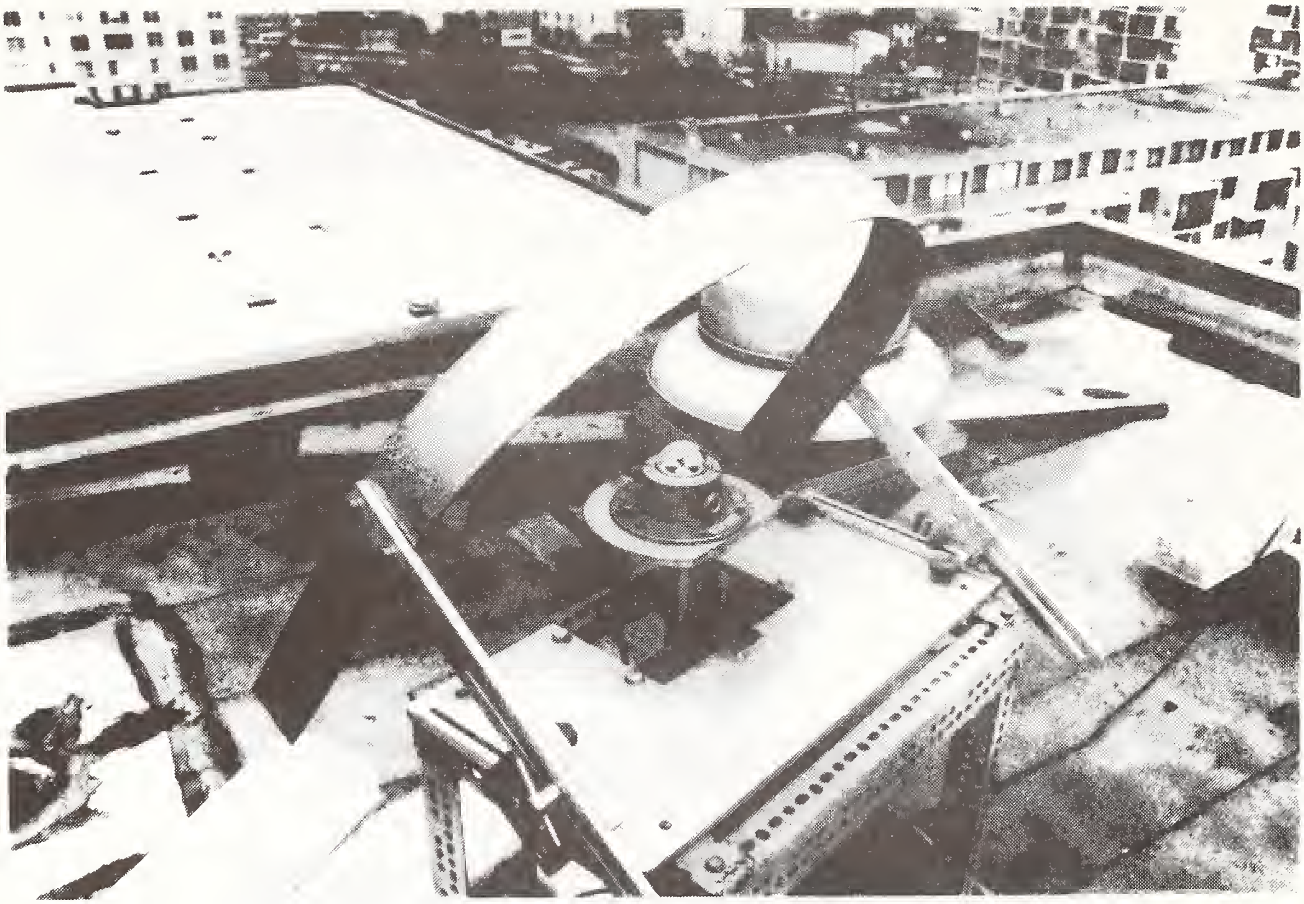

Figure 32 Indirect solar insolation measurement. This measurement requires shielding of direct solar radiation using a "shadow band". The shadow band must be repositioned every week to correct for seasonal changes in sun angle.

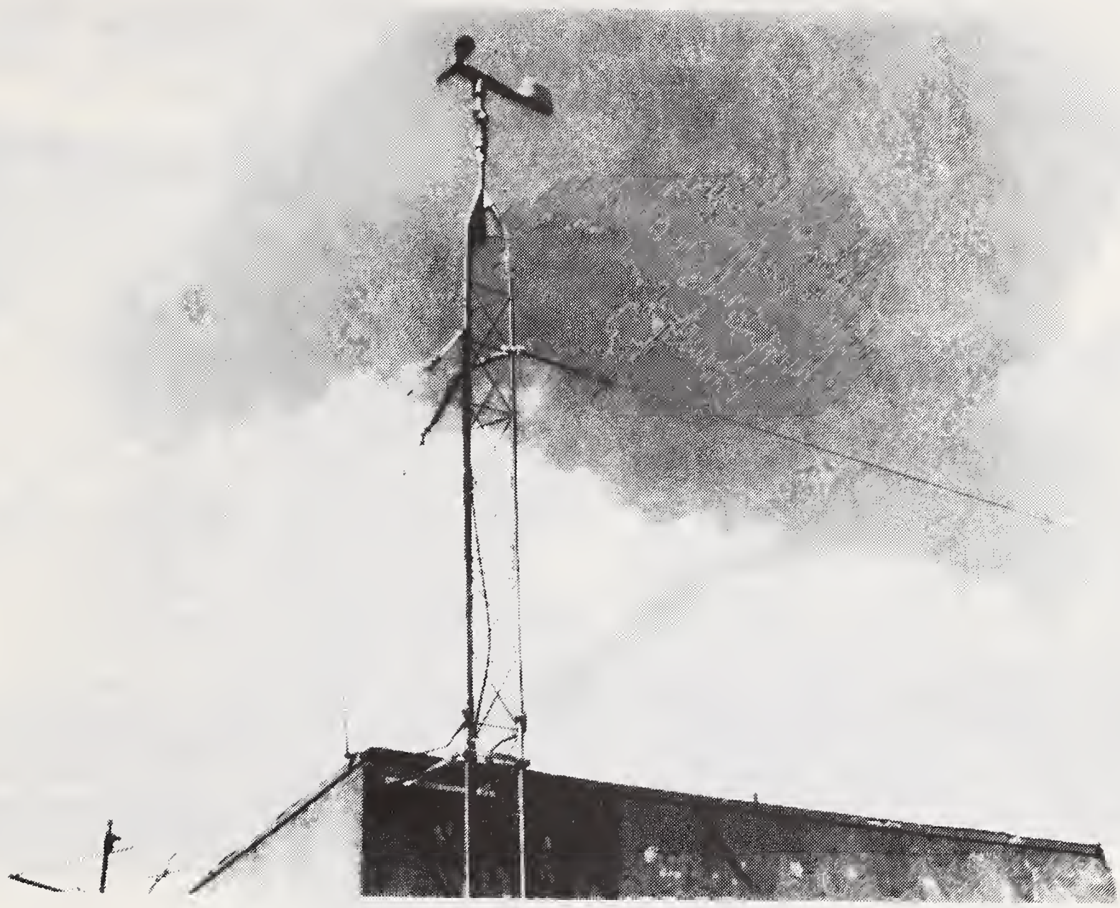

Figure 33 The aerovane and tower located on top of the 17 story Camci building. The aerovane measures wind speed and direction.

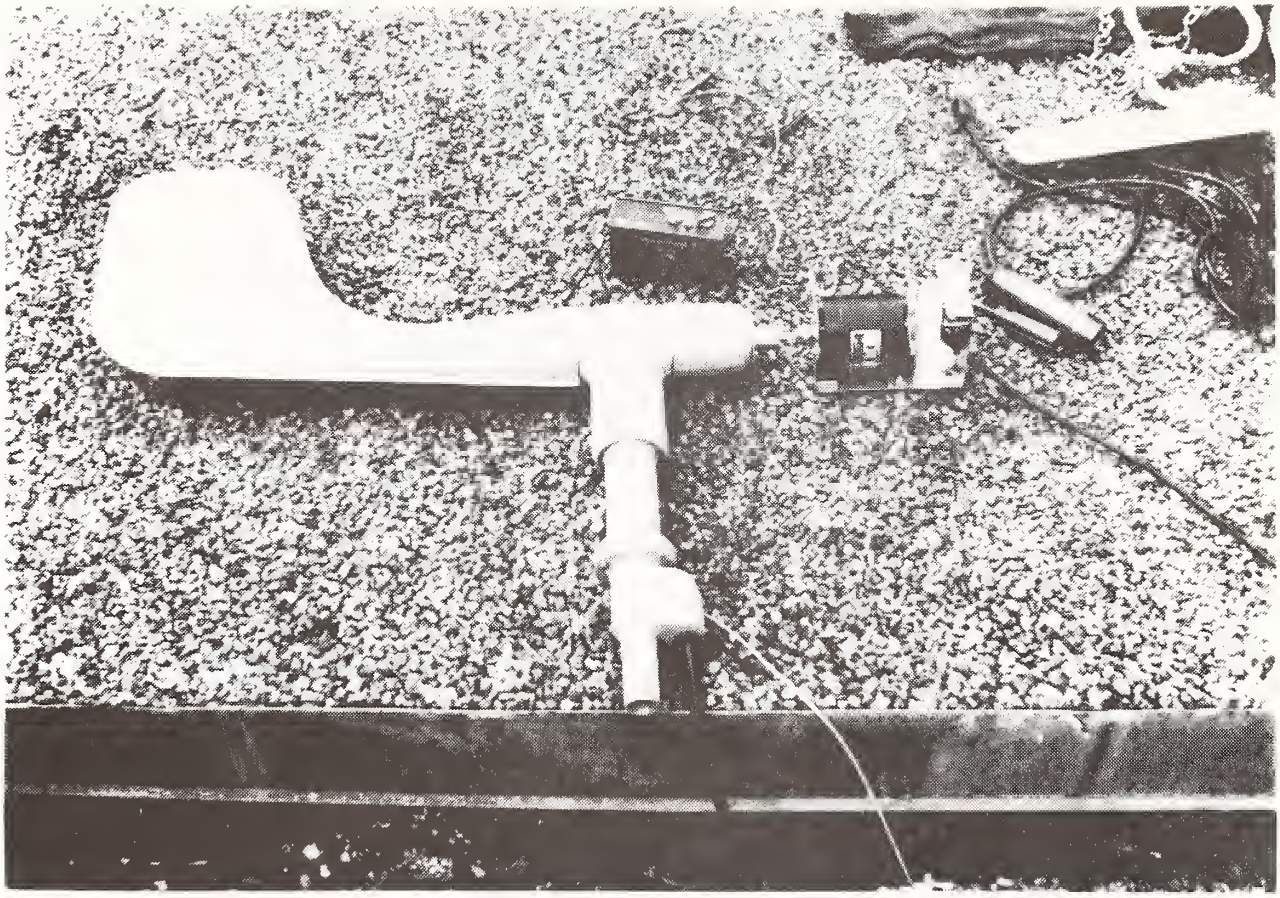

Figure 34 Aerovane wind direction and speed indicator. The propeller is removed to calibrate the speed indicator using a synchronous motor.

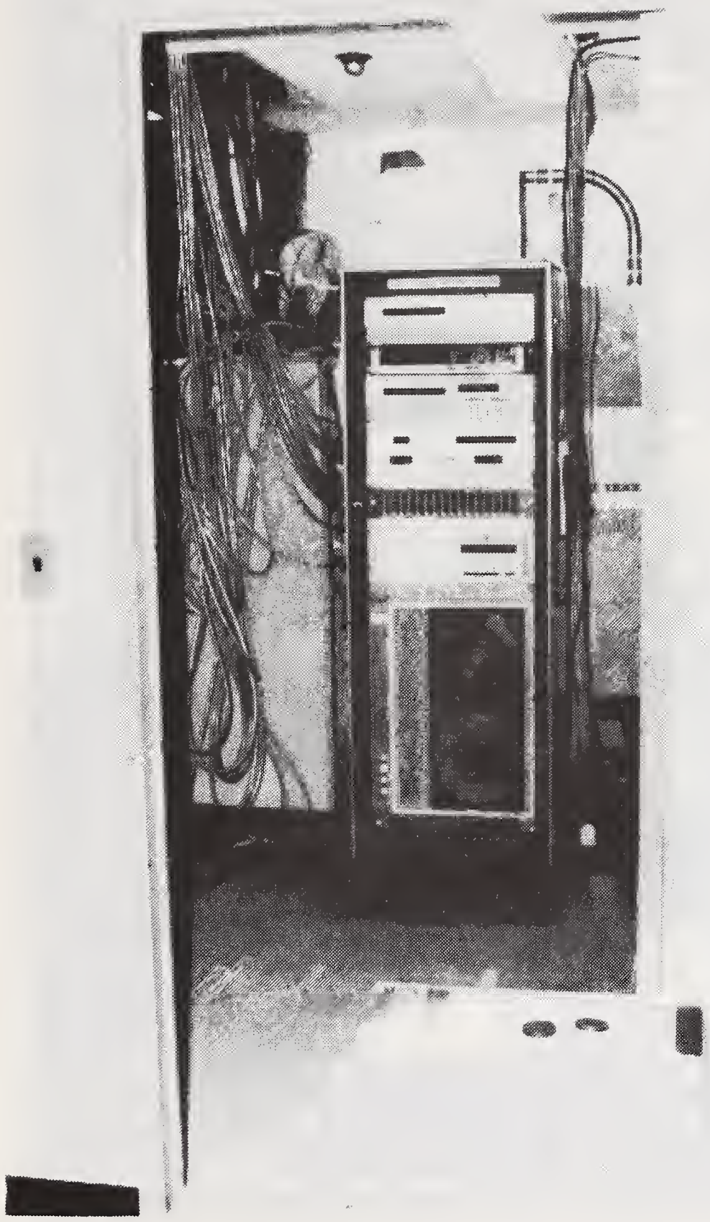

Figure 35 The central station of the Data Acquisition System (DAS) is located in the CEB.

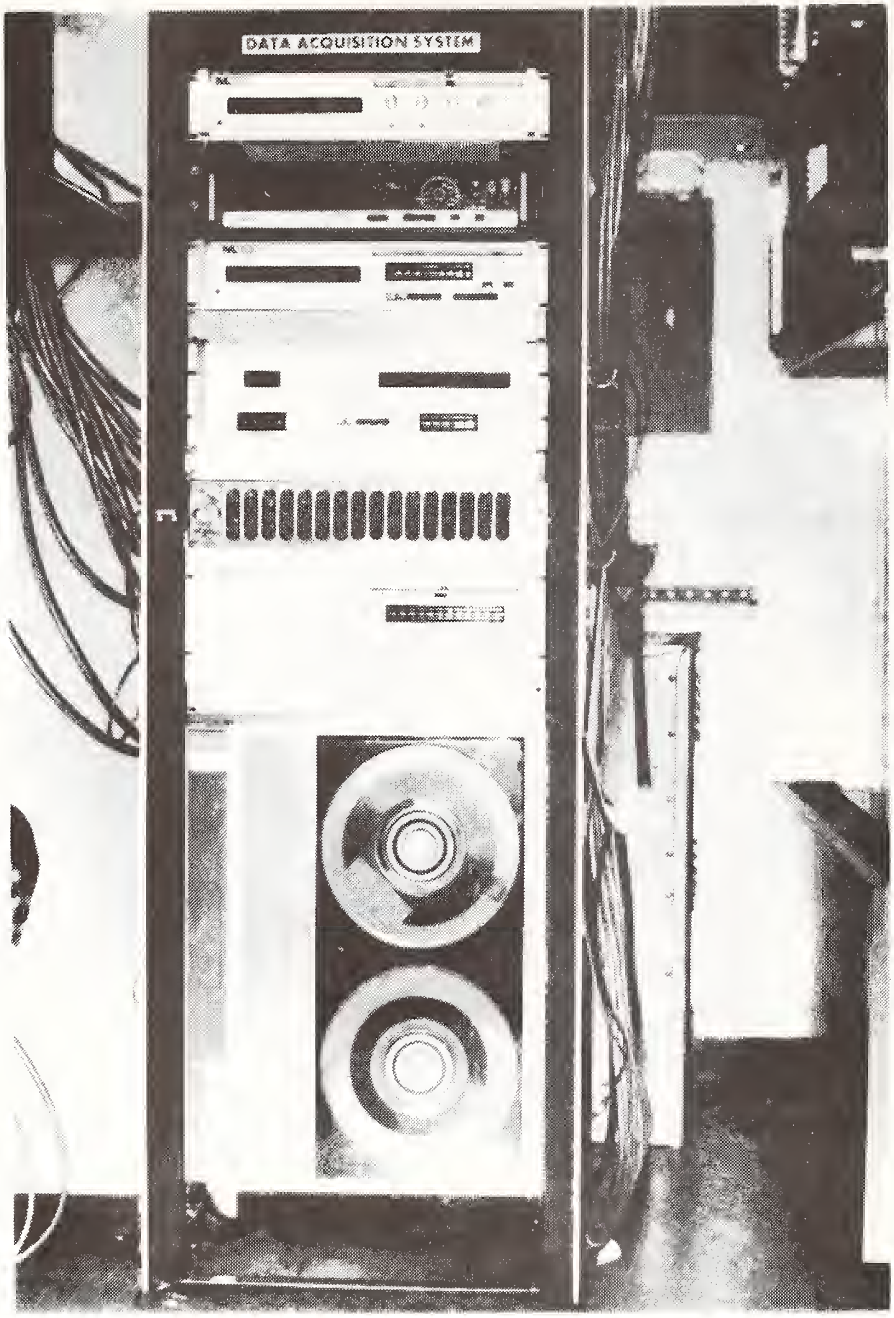

Figure 36 The central station of the DAS.

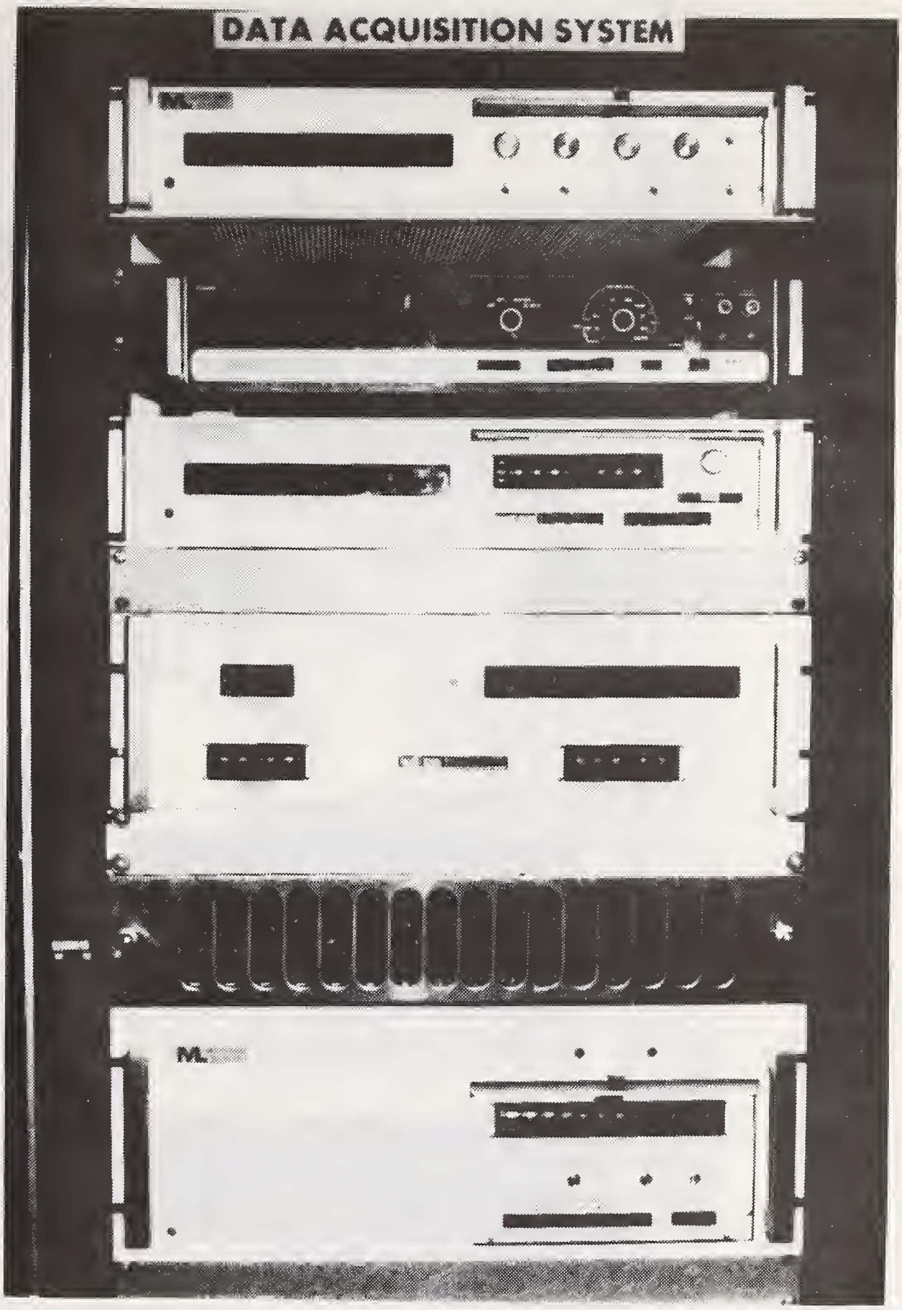

Figure 37 Close up view of DAS components. From top to bottom; digital system clock, digital volt meter, scanner, scanner control, coupler.

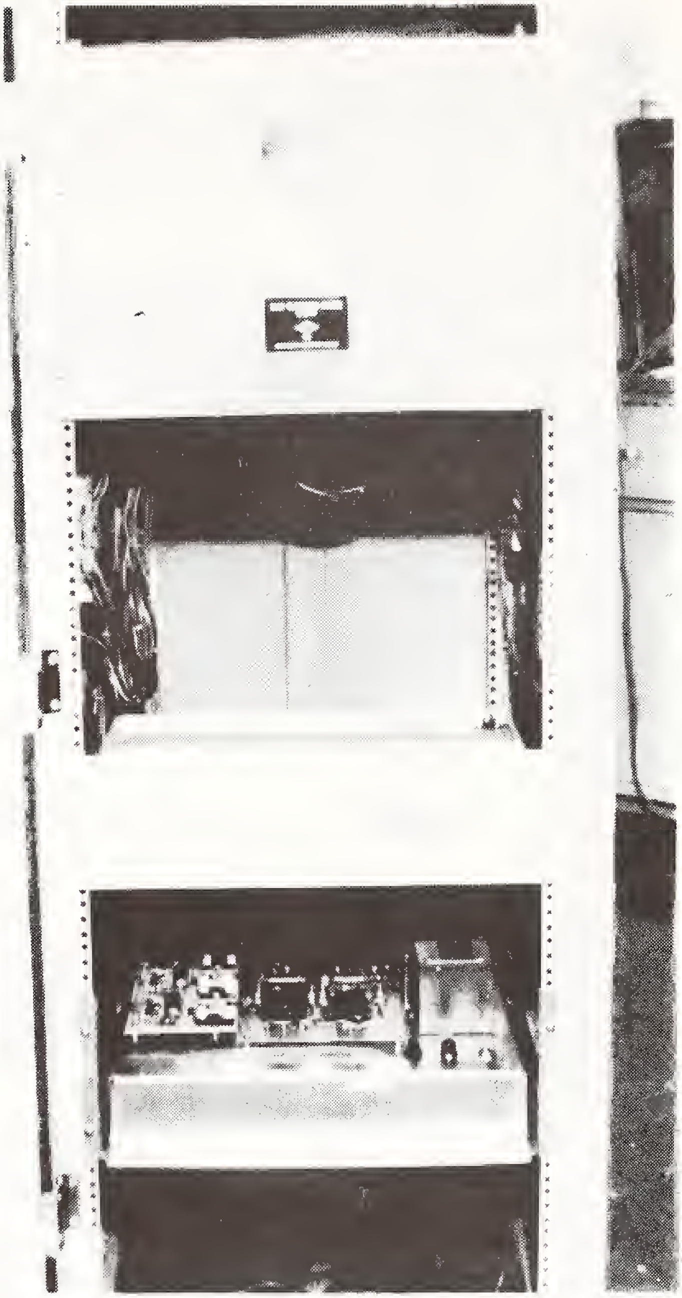

Figure 38 Front view of a remote DAS station rack. Each remote building has a similar cabinet that contains multiplexing circuitry, thermocouple reference, and watt transducers.

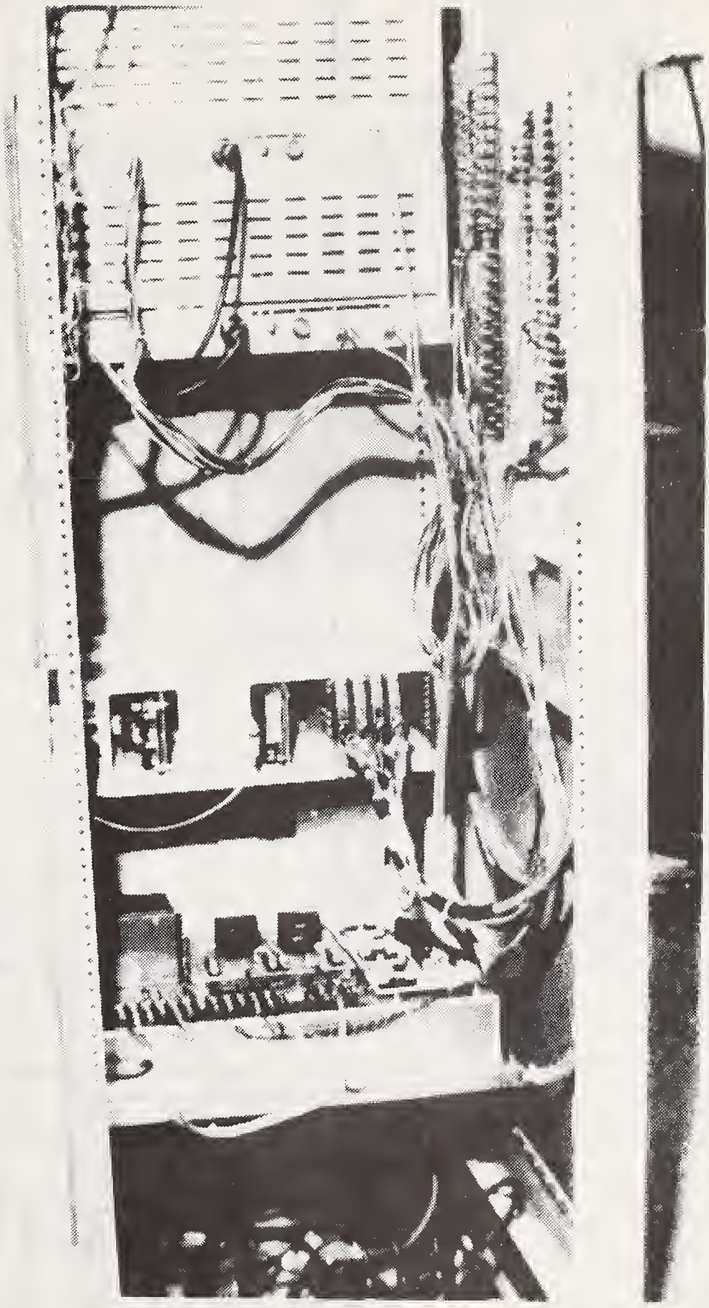

Figure 39 Rear view of a DAS remote station rack.

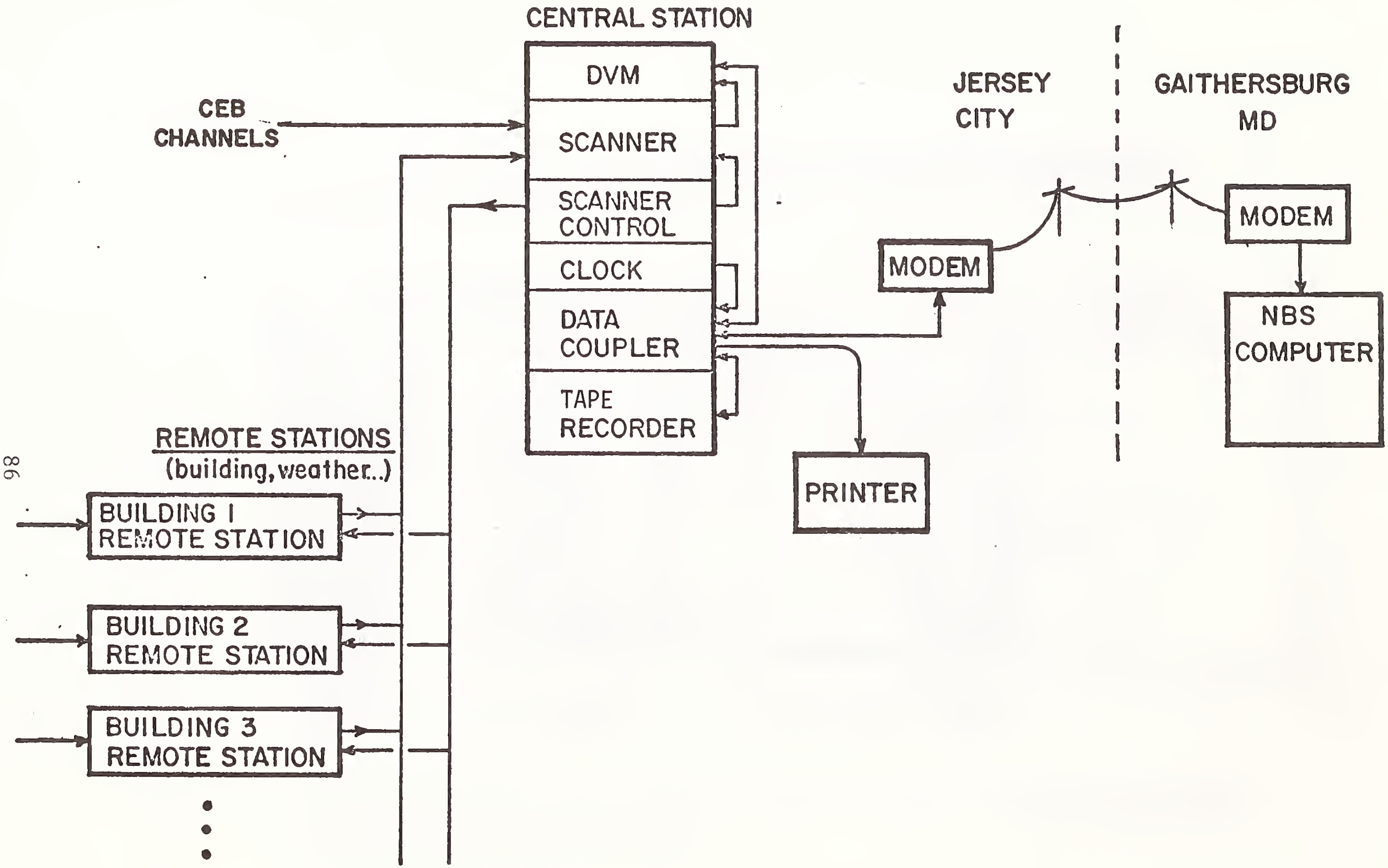

Figure 40 Block diagram of data acquisition system including printer and modem output capabilities.

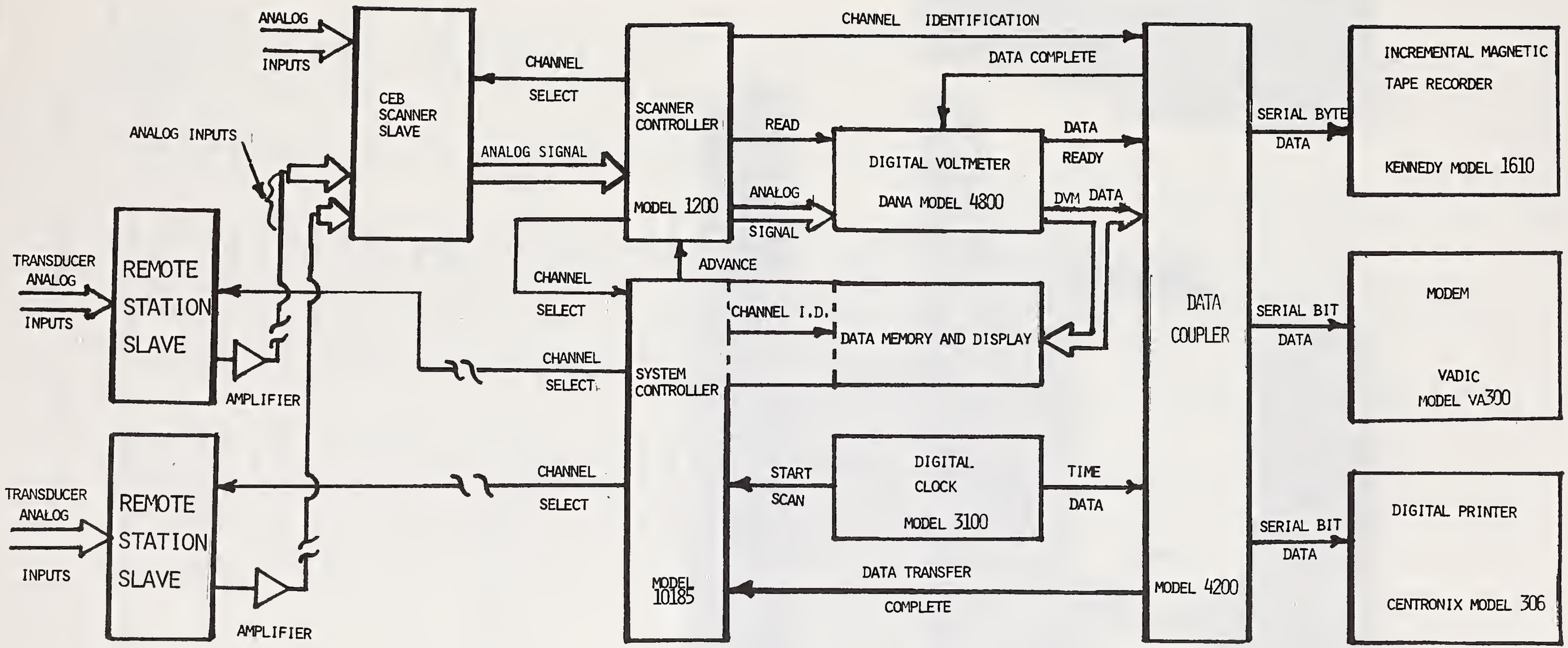

Figure 41 Schematic of DAS control signals and data flow from the transducers to the output devices. Two of the eight remote slave scanners are shown.

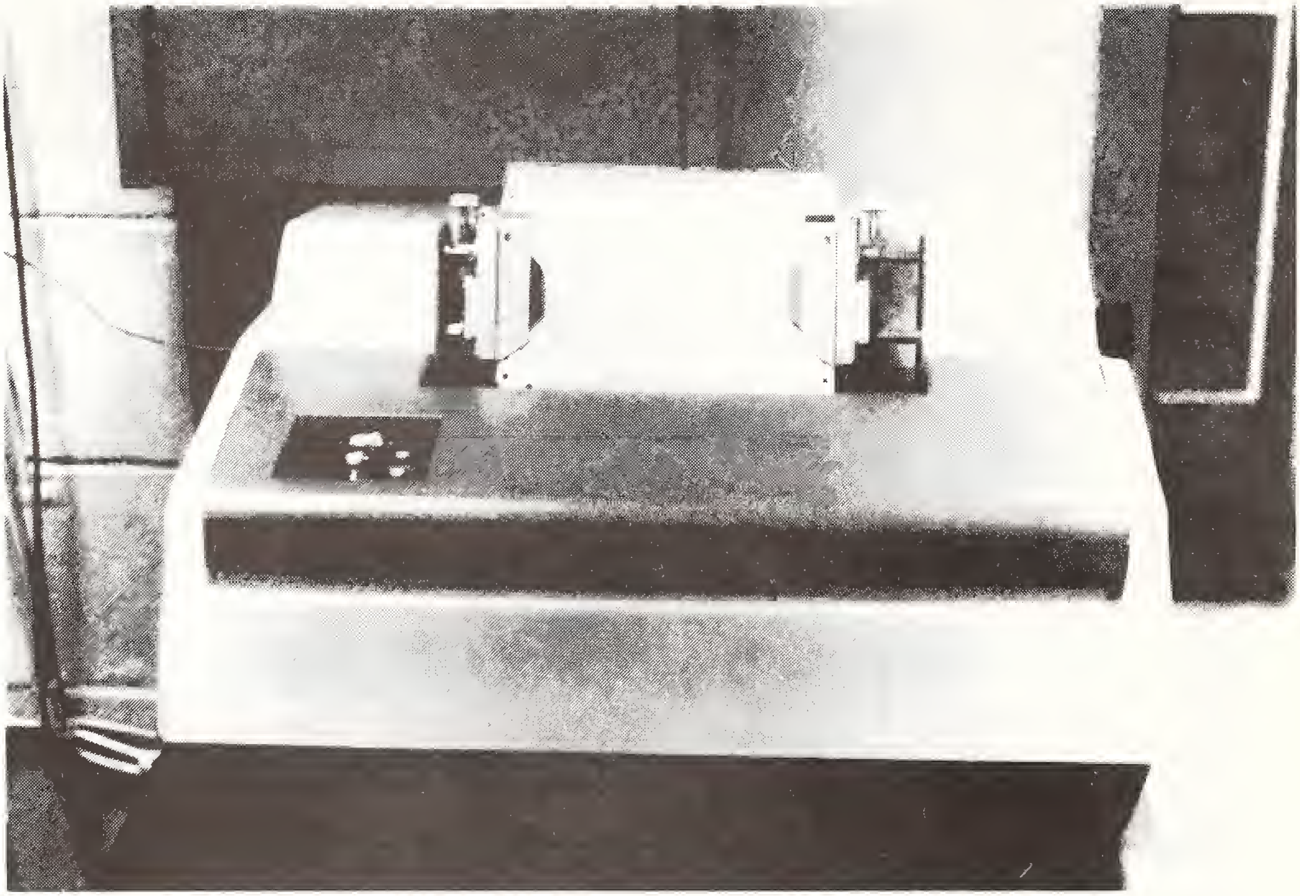

Figure 42 The printer provides a hard copy record of DAS scan data.

```
049075078NBS0490758
00200V+022935 00300V+034945 00400V+025815 00500V+027605 00600V+036735
00700V+030205 00800V+078735 00900V+048715 00201V+045395 00301V-000175
00401V+022935 00501V+026955 00601V+026855 00701V+034375 00801V+032855
00901V+023625 00202V+025865 00302V+014115 00402V+021995 00502V+026265
00602V-013875 00702V-018505 00802V+043625 00902V+033295 00203V+032535
00303V-000165 00403V+019545 00503V+025335 00603V+020575 00703V+020515
00803V+023455 00903V+043475 00204V+042095 00304V+001855 00404V+017635
00504V+024295 00604V+013385 00704V+034595 00804V+061705 00904V+000875
00205V+005505 00305V+092505 00405V+027985 00505V+024775 00605V+052995
00705V+057515 00805V+021815 00905V+009545 00206V+009295 00306V+045615
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00906V+037875 00207V+034545 00307V+016035 00407V+028315 00507V+025835
00607V+040115 00707V+037385 00807V+008655 00907V+061155 00208V+058105
00308V+030395 00408V+028515 00508V+026155 00608V+058995 00708V+065785
00808V+033165 00908V+066225 00209V+065045 00309V+027595 00409V+028385
00509V+026455 00609V+012405 00709V+000105 00809V+006835 00909V+015175
00210V+019735 00310V+031255 00410V+028695 00510V+026735 00610V+034285
00710V+018535 00810V+017085 00910V+034155 00211V+032745 00311V+031495
00411V+028955 00511V+026985 00611V+034415 00711V+033465 00811V+033415
00911V+000145 00212V+003735 00312V-000165 00412V+025705 00512V+026815
00612V+000295 00712V+033405 00812V+033655 00912V+000155 00213V+000675
00313V-000165 00413V+022855 00513V+026255 00613V+000295 00713V+000085
00813V+000125 00913V+000155 010   V+066185 011   V+020765 012   V+067295
013   V+018335 014   V+038295 015   V+061165 016   V+056365 017   V+052225
018   V+020345 019   V+041125 020   V+054615 021   V+020505 022   V+020515
023   V+019755 024   V+020405 025   V+020725 026   V+064115 027   V+019815
028   V+019855 029   V+020355 030   V+051135 031   V+000065 032   V+000035
033   V+024435 034   V+050475 035   V+000295 036   V+050705 037   V+032075
038   V+012545 039   V+000165 040   V+002415 041   V+009635 042   V-000165
043   V+016725 044   V+000025 045   V+032985 046   V+011705 047   V+005685
048   V-001605 049   V-000285 050   M+035102 051   M+035292 052   M+036502
053   M+035092 054   M+037122 055   M+038102 056   M+038342 057   M+035362
058   M+036482 059   M+035222 060   M+034772 061   M+011012 062   M+010932
063   M+018482 064   M+011552 065   M+008092 066   M+011052 067   M+010732
068   M+009702 069   M+009692 070   M+010922 071   M+009762 072   M+010412
073   M+035242 074   M+010702 075   M+010542 076   M+011732 077   M+012162
078   M+009892 079   M+010032 080   M+100602 081   M+039702 082   M+023272
083   M+154432 084   M+028312 085   M+112772 086   M-000442 087   M+018562
088   M+008752 089   M+017822 090   M-001152 091   M+016442 092   M-004692
093   M+001042 094   M+029662 095   M+200002 096   M-004002 097   M+026132
098   M+021932 099   M+031592 100   M+015612 101   M+004492 102   M-001062
103   M-121002 104   M-012732 105   M-019362 106   M-001012 107   M+019032
108   M-000232 109   M-000022 110   V+014535 111   V+046785 112   V+043085
113   V+000025 114   V+001885 115   V+029195 116   V+033105 117   V+000085
118   V+044195 119   V+041365 120   V+041305 121   V+041265 122   V+041235
123   V+041195 124   V+041065 125   V+041045 126   V+041015 127   V+040985
128   V+040955 129   V+040845 130   V+040815 131   V+040795 132   V+040765
133   V+040745 134   V+040645 135   V+040625 136   V+040595 137   V+040575
138   V+040545 139   V+040445 140   V+043305 141   V+048575 142   V+021135
143   V+089155 144   V+034015 145   V+045595 146   V+064545 147   V+062115
148   V+062285 149   V+062195 150   V+062195 151   V+062175 152   V+062155
153   V+062135 154   V+062055 155   V+062035 156   V+062025 157   V+061995
158   V+061975 159   V+061885 160   V+004966 161   V+000076 162   V+000026
163   V+004646 164   V+000026 165   V+000016 166   V+000026 167   V+000026
168   V+000026 169   V+000026 170   V-000043 171   V-000043 172   V+046255
173   V+045855 174   V+012815 175   V+013165 176   V+013325 177   V+030005
178   V+025405
```

Figure 43 Example of printer output.

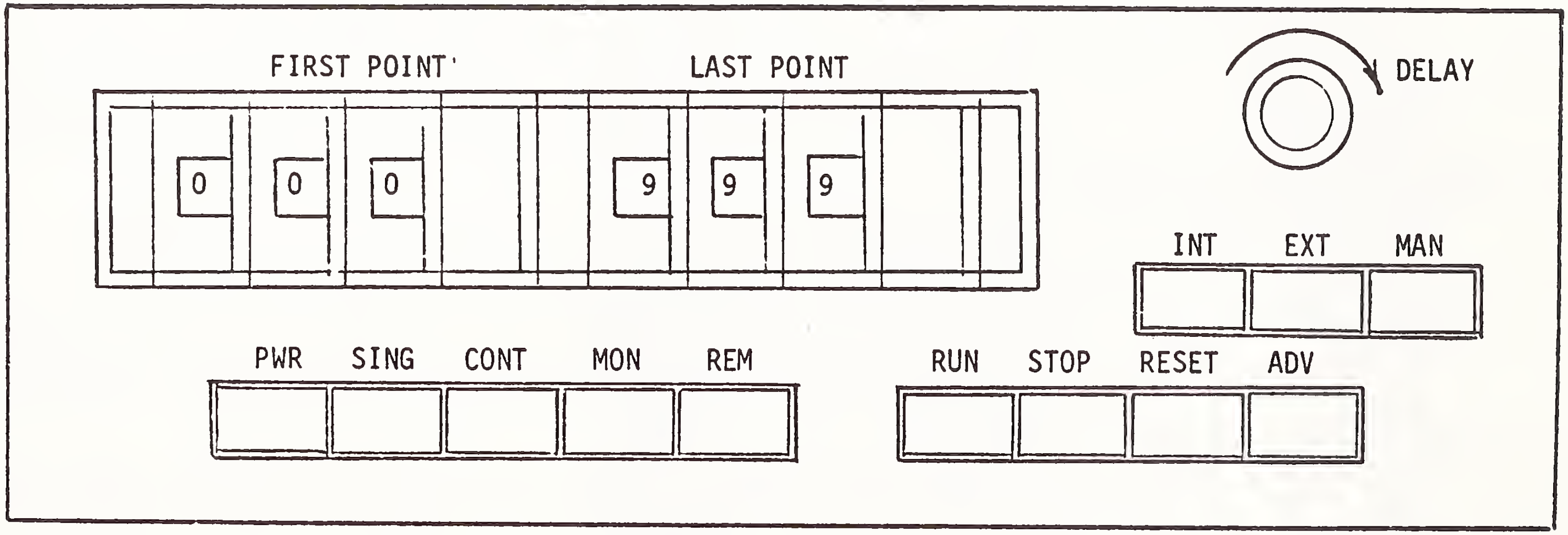


Figure 44 Scanner controller front panel controls.

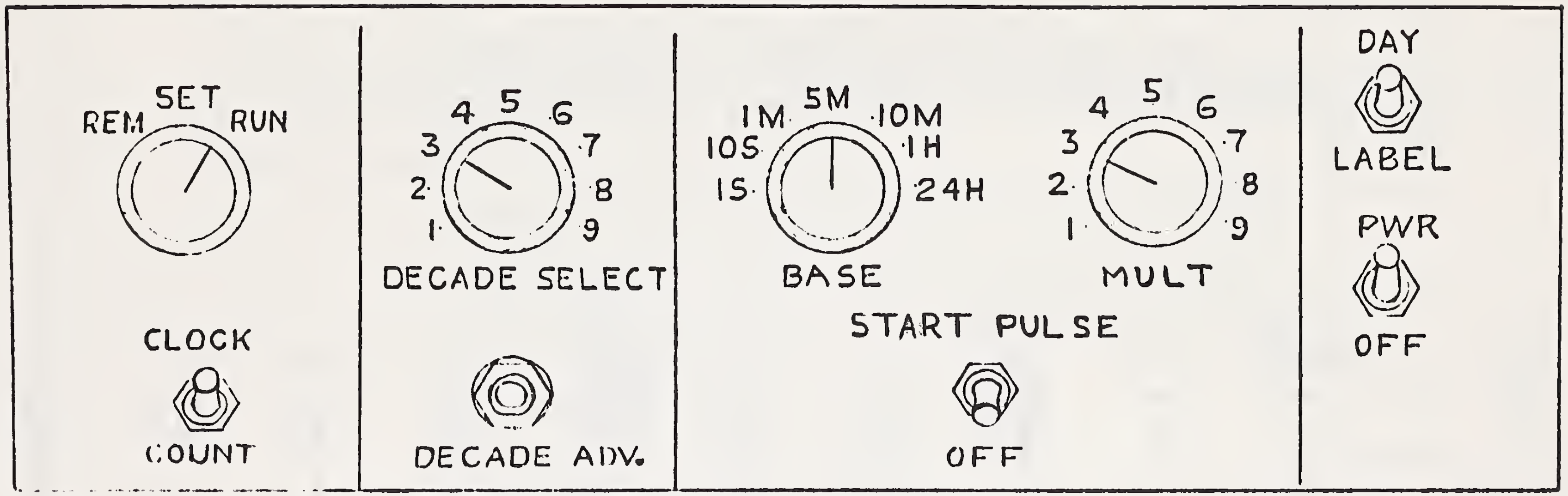


Figure 45 Front panel controls of the digital clock.

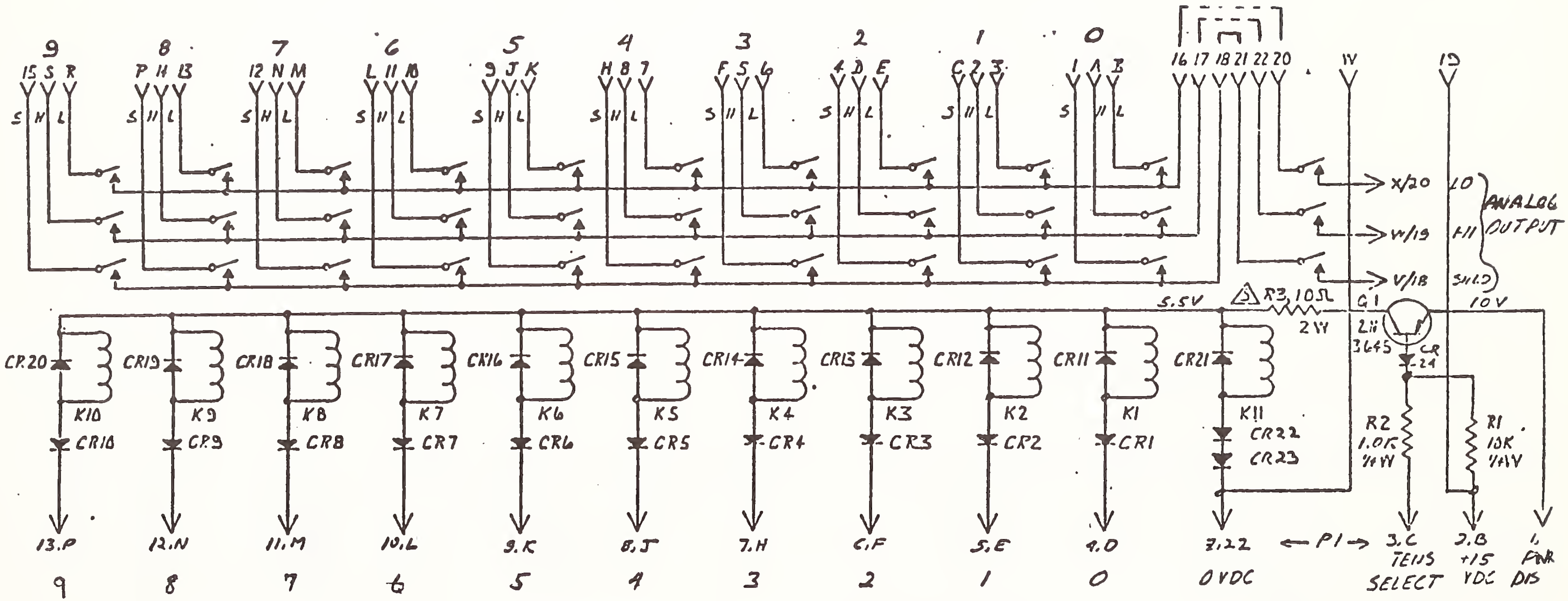


Figure 46 Schematic of relay multiplexing cards in the CEB and remote slave scanners. 10 analog signal inputs are connected at the top pins, relay select lines are at the bottom.

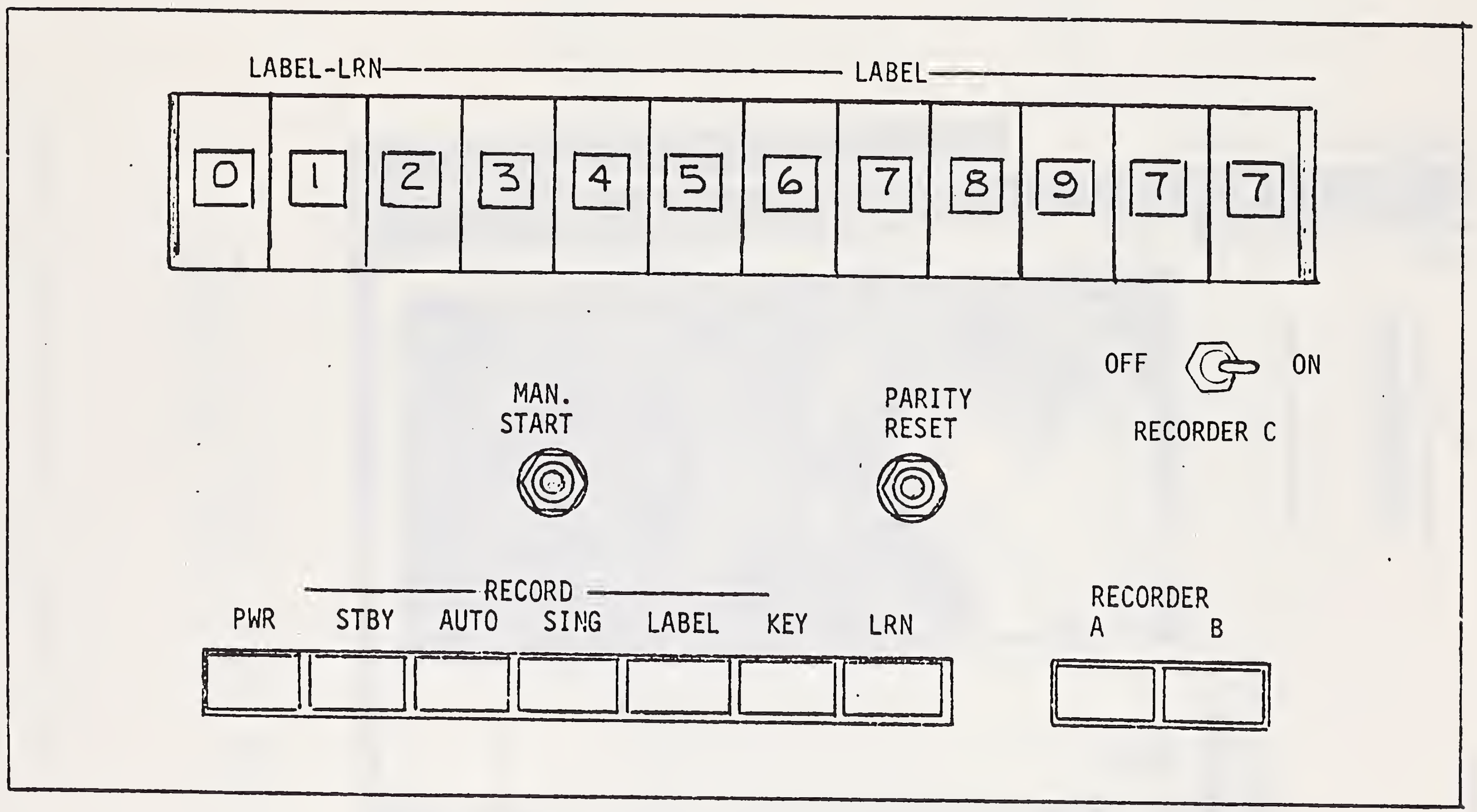


Figure 47 Front panel controls of the data coupler.

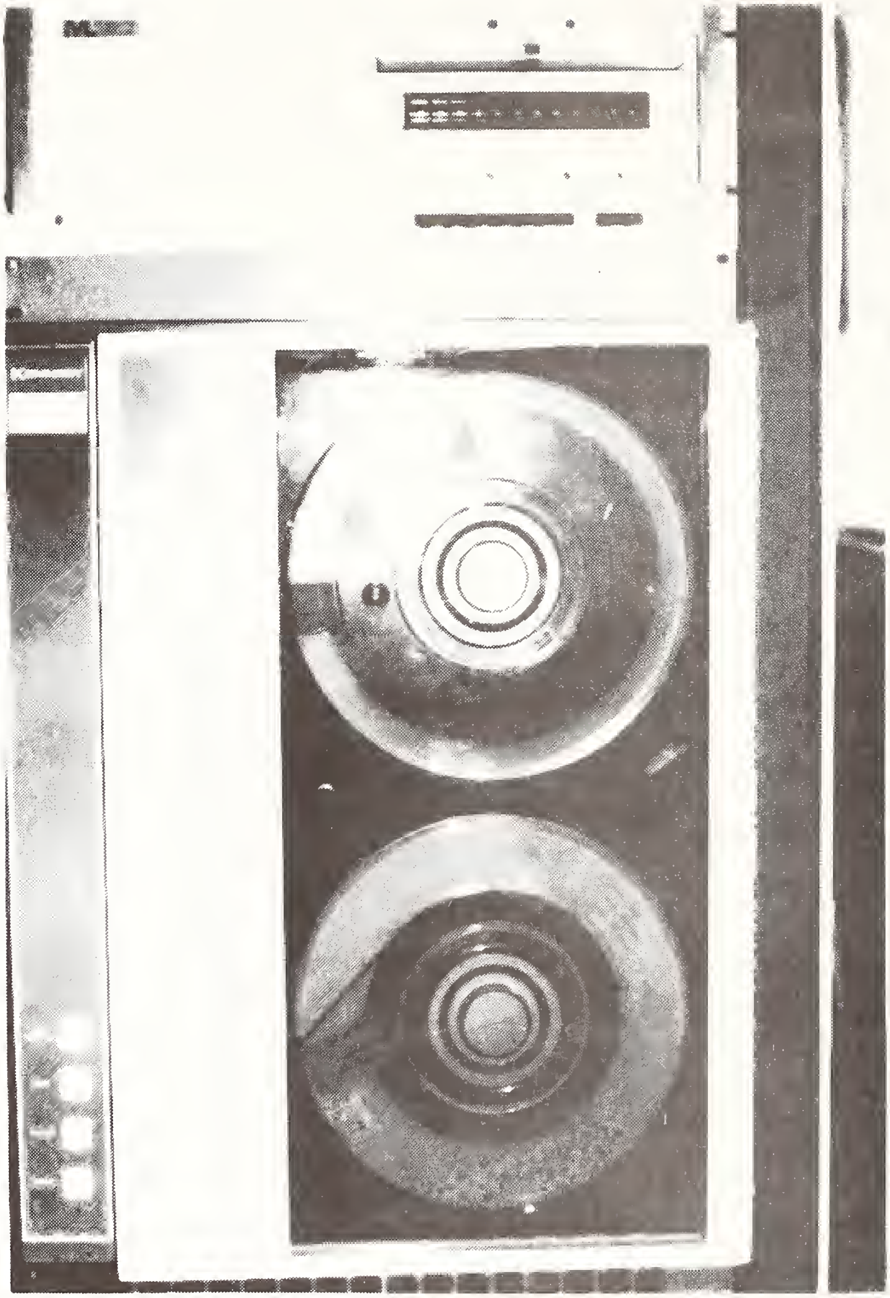


Figure 48 The DAS digital incremental tape recorder.

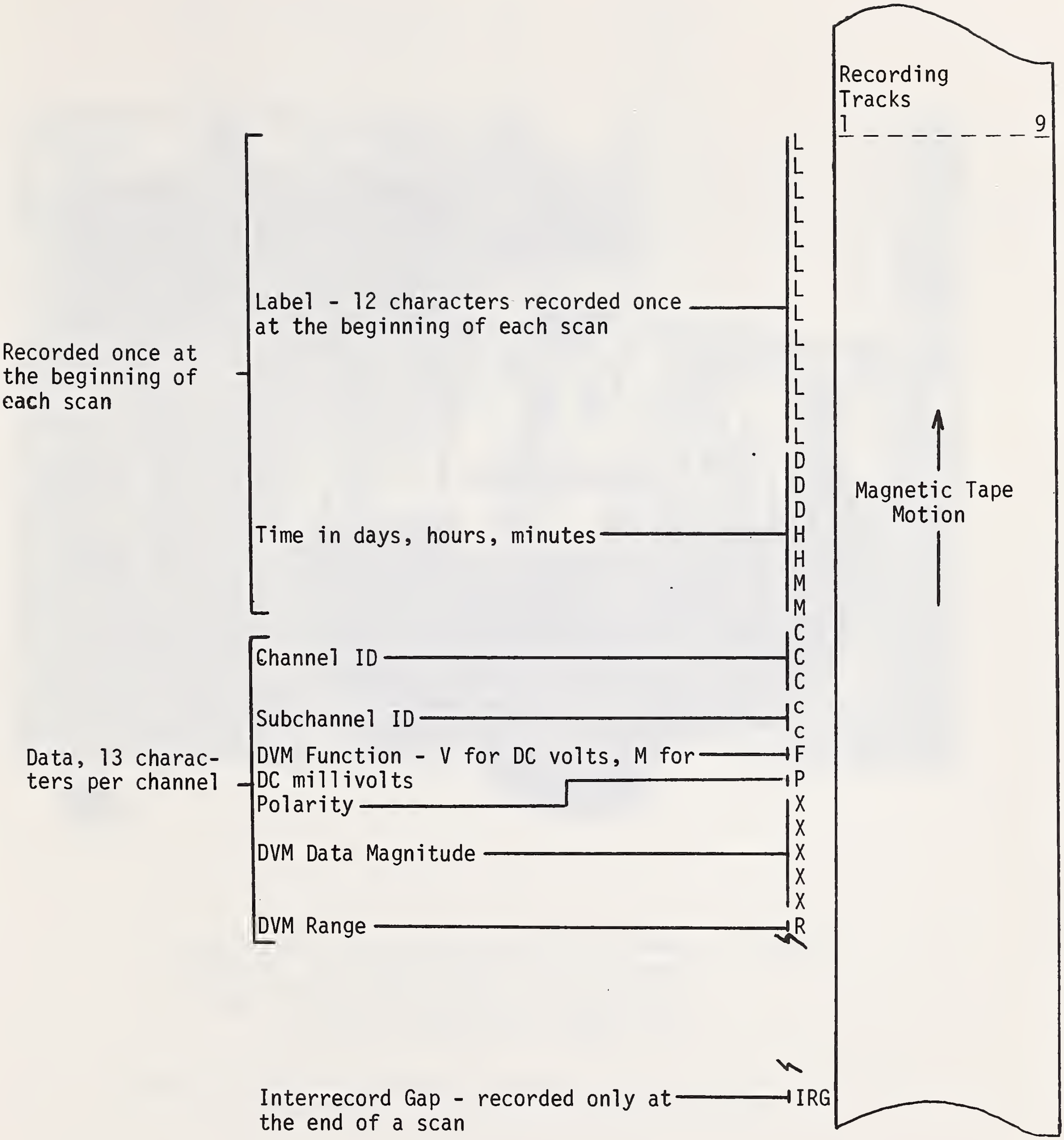


Figure 49 DAS output format for magnetic tape.

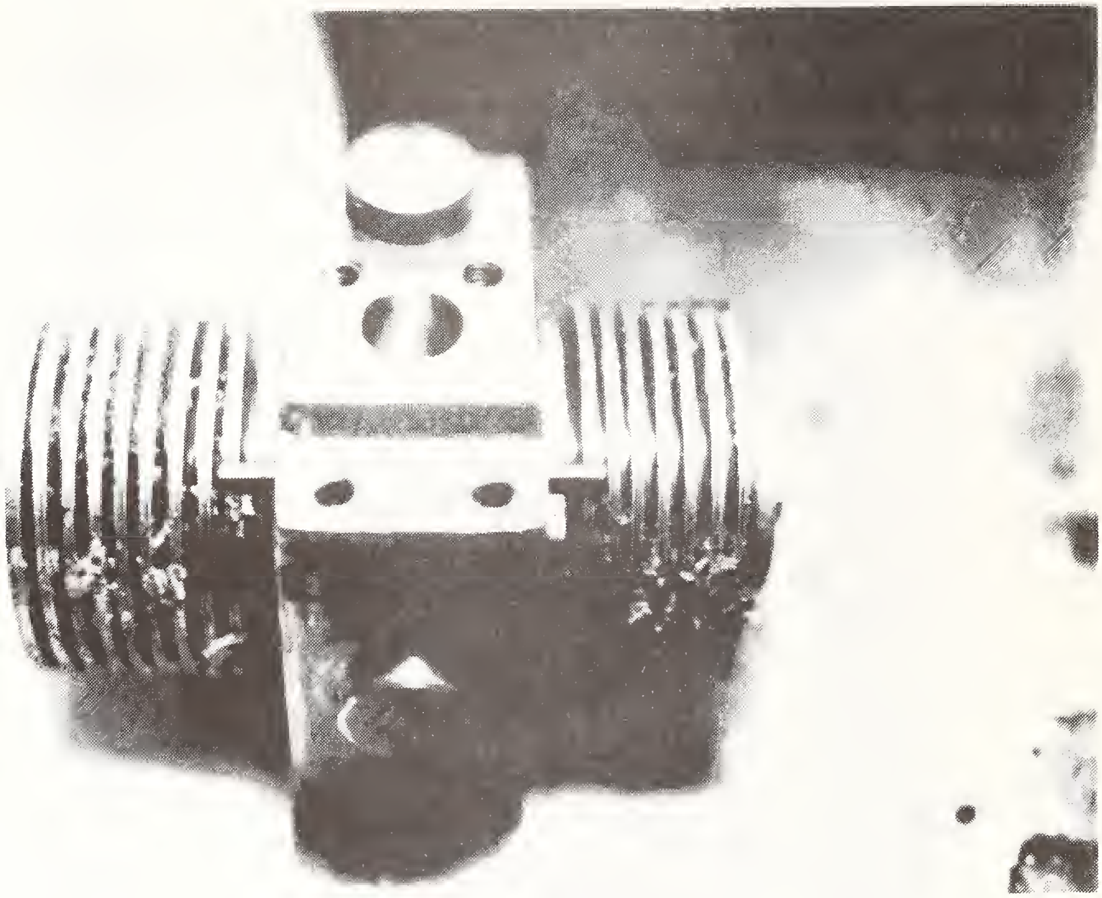


Figure 50 Example of fouled bellows in a differential pressure cell. The accumulation of fouling was reduced by frequent bleeding of the cell chambers and venturi lines.

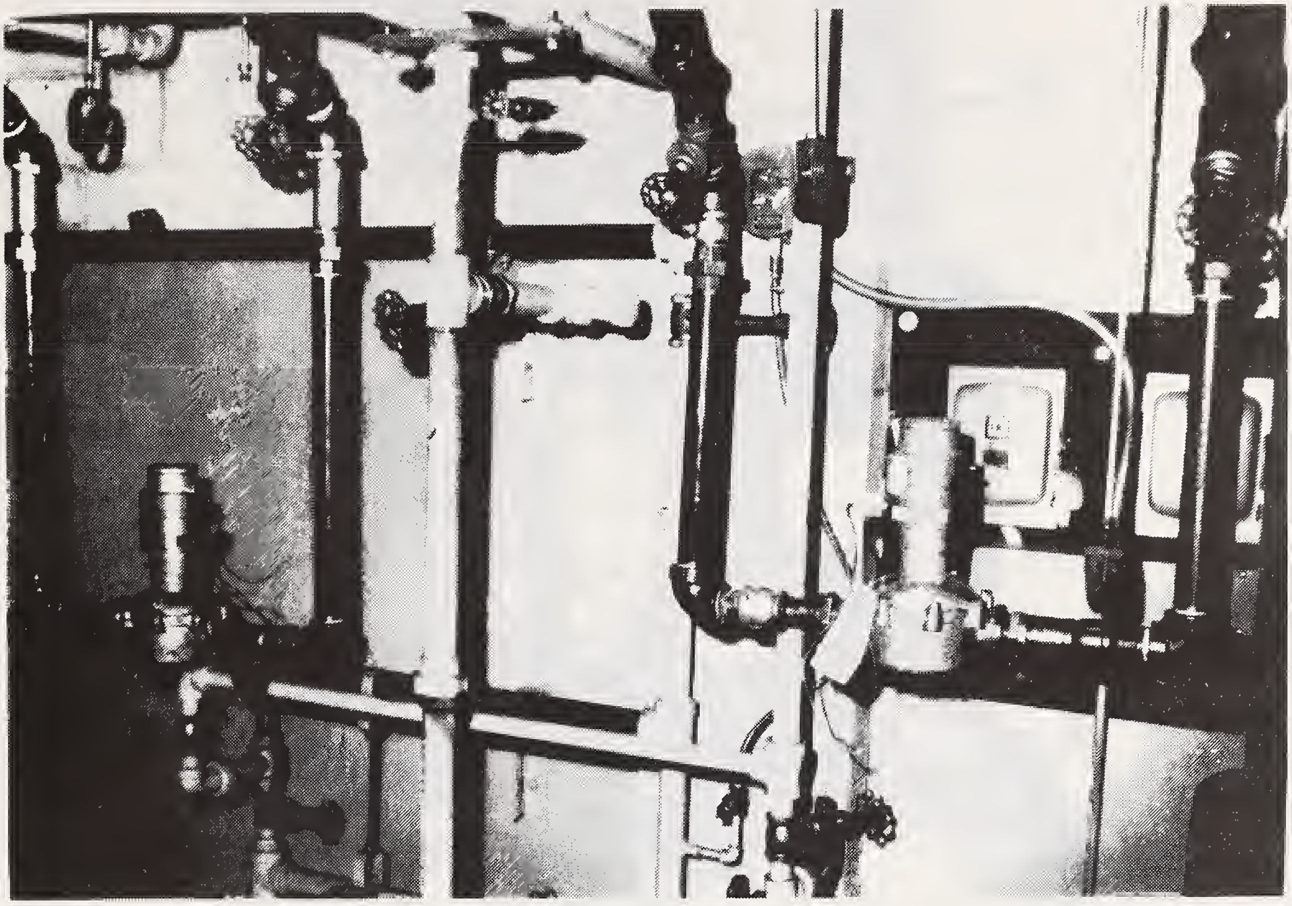


Figure 51 Nutating disk meters installed in day tank fuel lines.

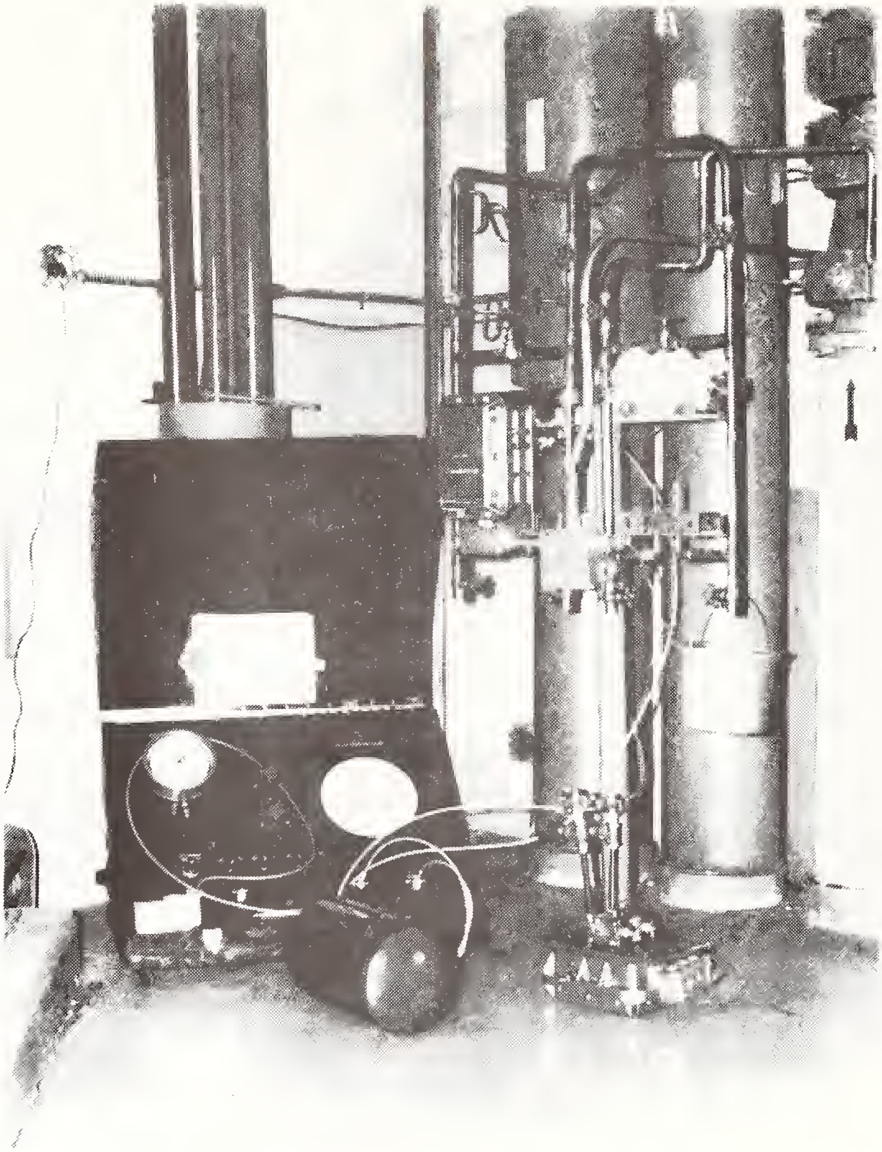
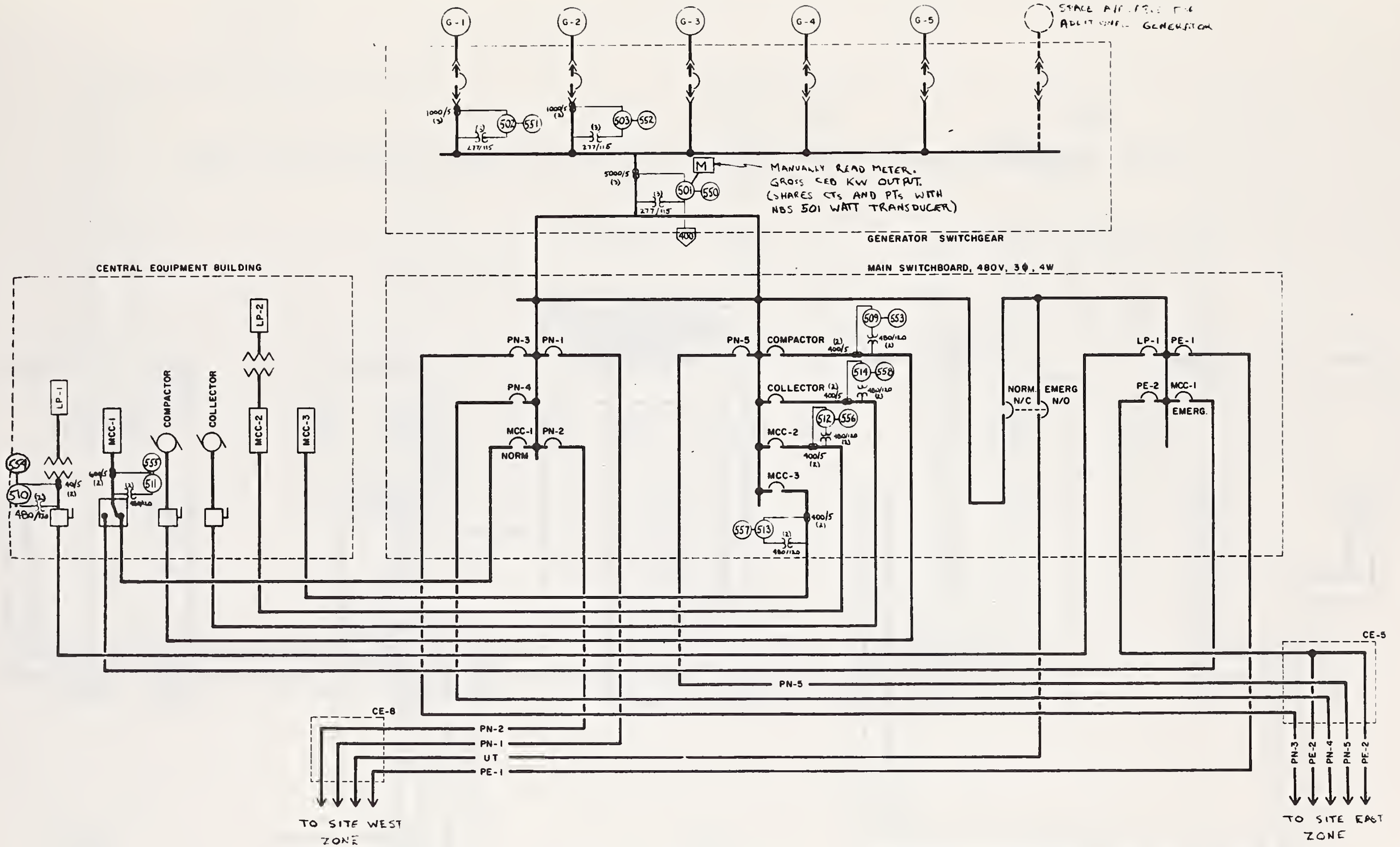


Figure 52 Portable calibration unit for differential pressure cells.

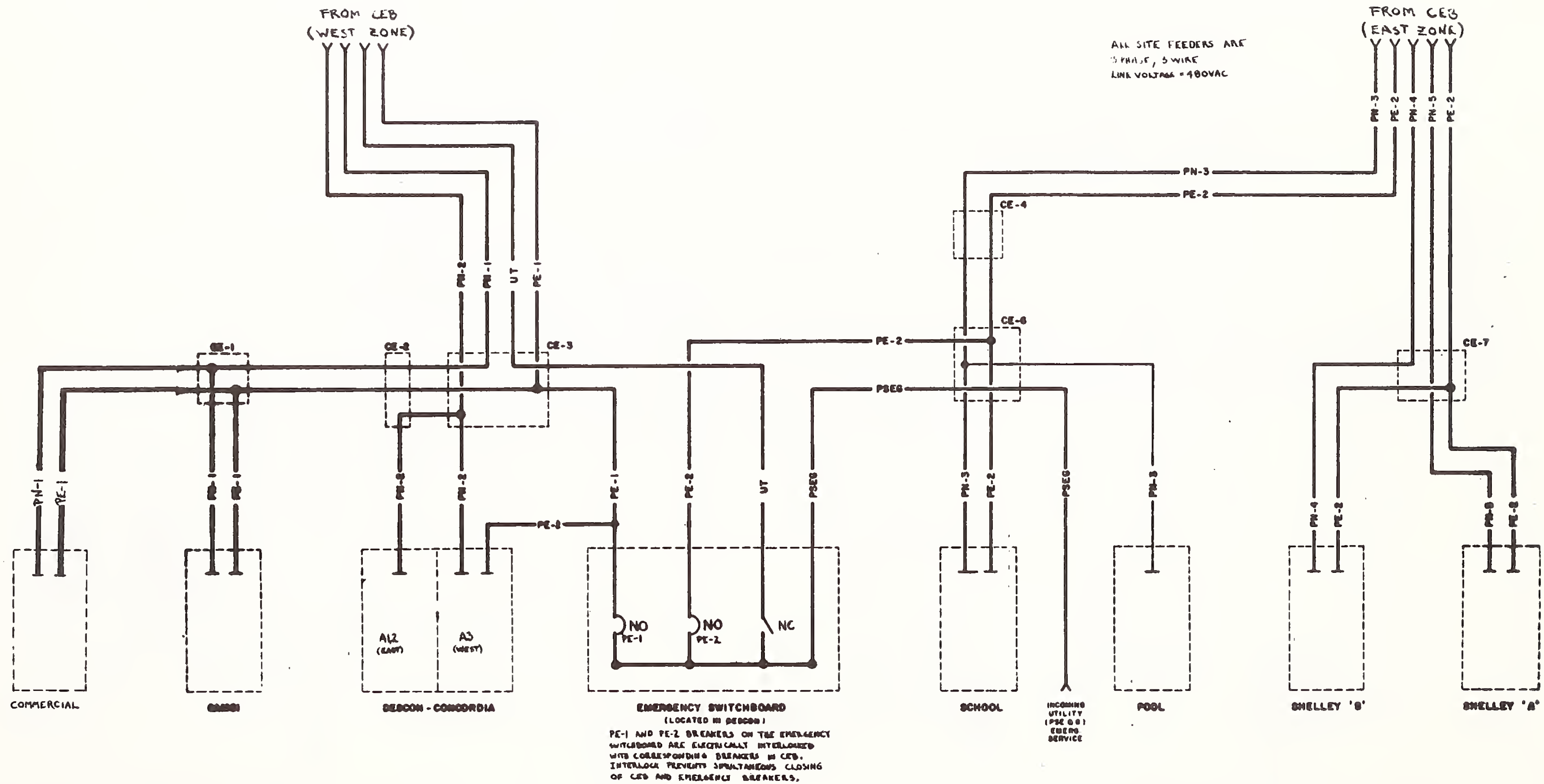
REFERENCES

1. Monitor Labs Model 10185 Multichannel Data Acquisition System Technical Manual
2. Monitor Labs Model 1200 Scanner Technical Manual
3. Monitor Labs Model 3100 Digital Clock Technical Manual
4. Monitor Labs Model 4200 Data Coupler Technical Manual
5. Dana Model 4800 Digital Voltmeter Instruction Manual
6. Kennedy Co. Model 1600 Incremental Magnetic Tape Recorder Technical Manual
7. Thermocouple Guide Book, Pall Trinity Micro Corp., Cortland, N.Y.

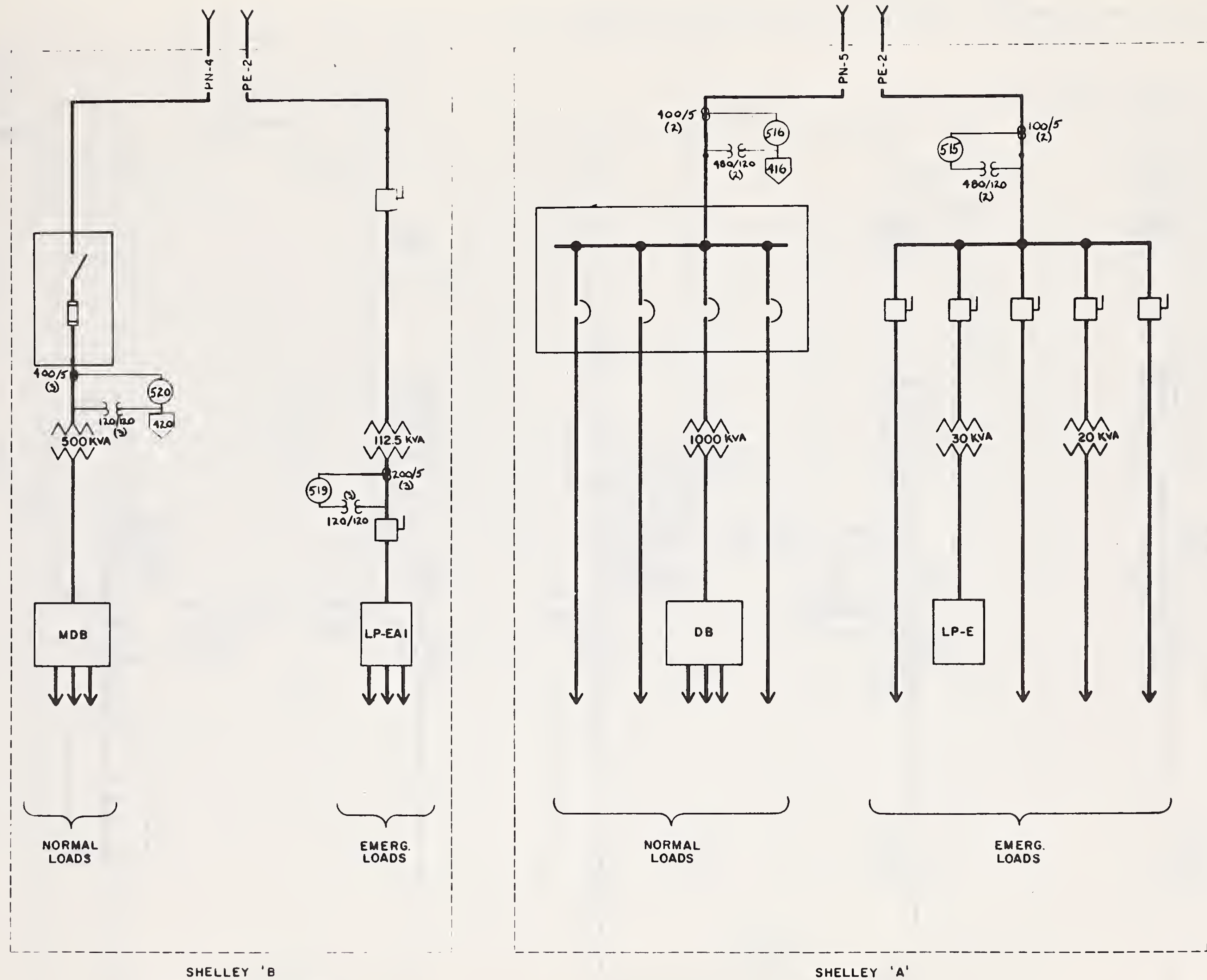
APPENDIX 1 : As-Built Drawings of Site Facilities and Instrument Locations



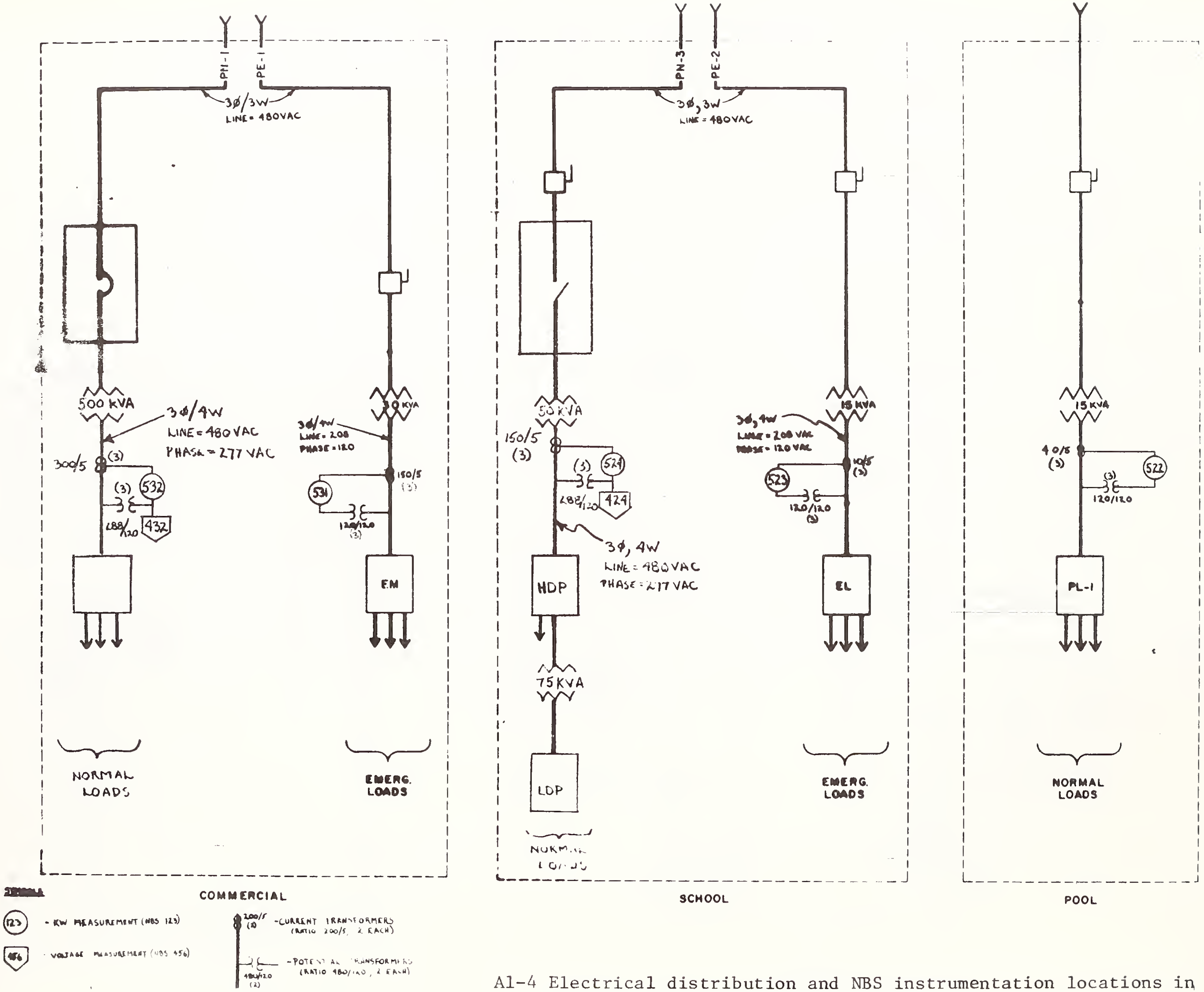
A1-1 Schematic of CEB electrical power generation and distribution. Locations of NBS instrumentation are shown. CE-5 and CE-8 are underground distribution vaults located outside of the CEB.



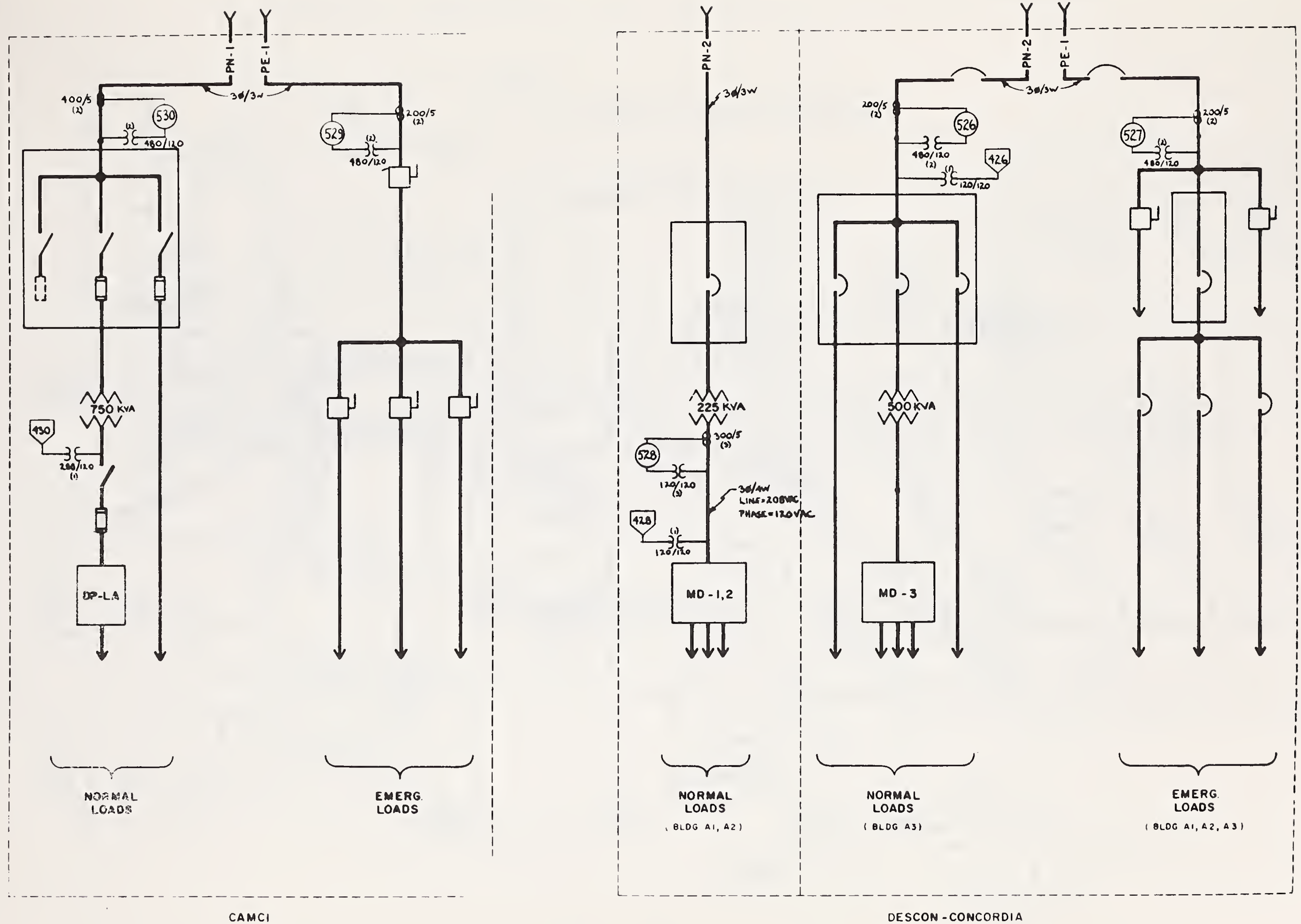
A1-2 Site electrical feeder distribution CE-1 thru 7 are underground distribution vaults.



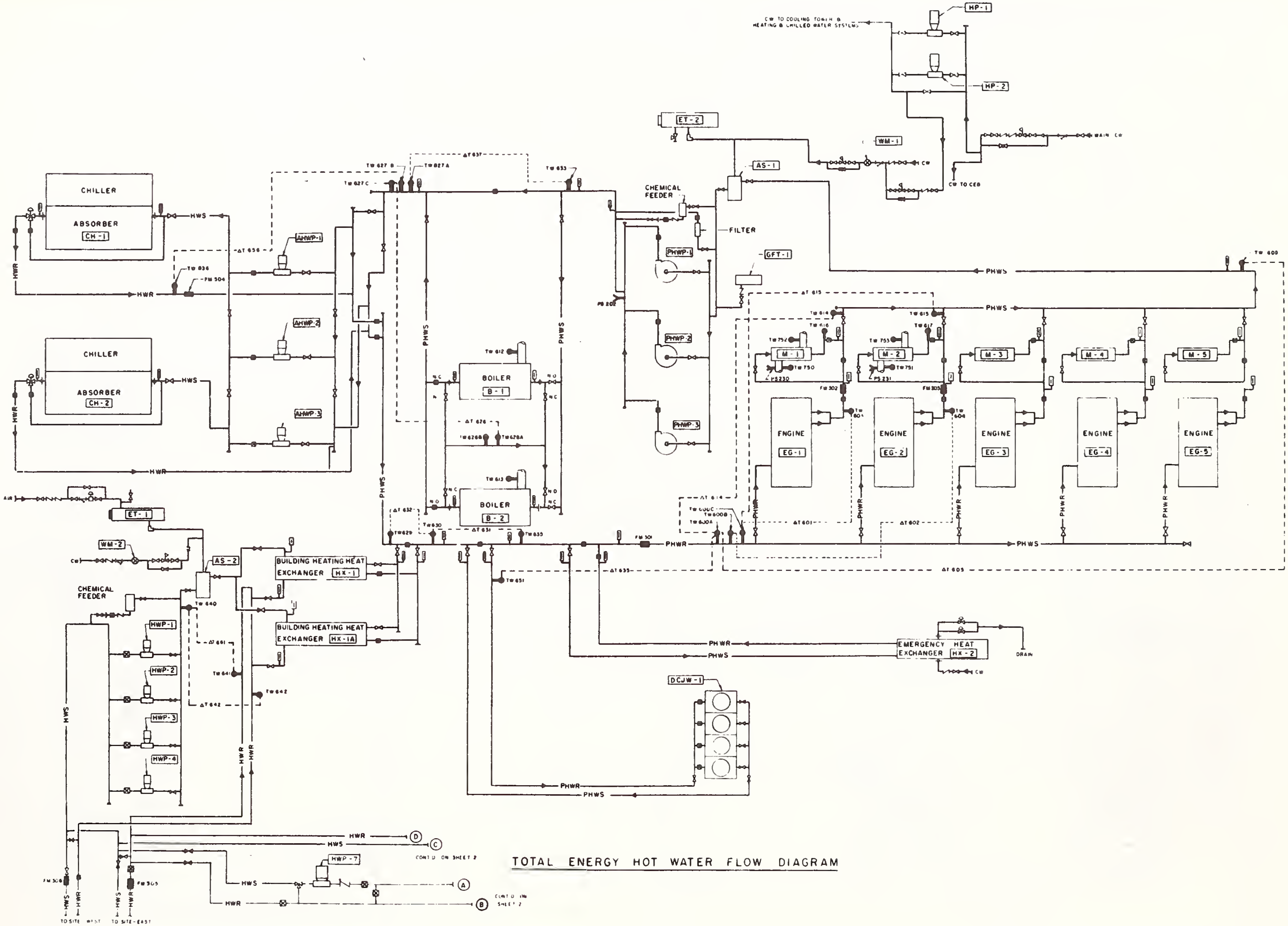
A1-3 Electrical distribution and NBS instrumentation locations in Shelley A and Shelley B. Normal loads are apartment lighting, outlets and cooking. Emergency loads are Comdor lighting, exit signs, fire alarm and pump system and at least one elevator.



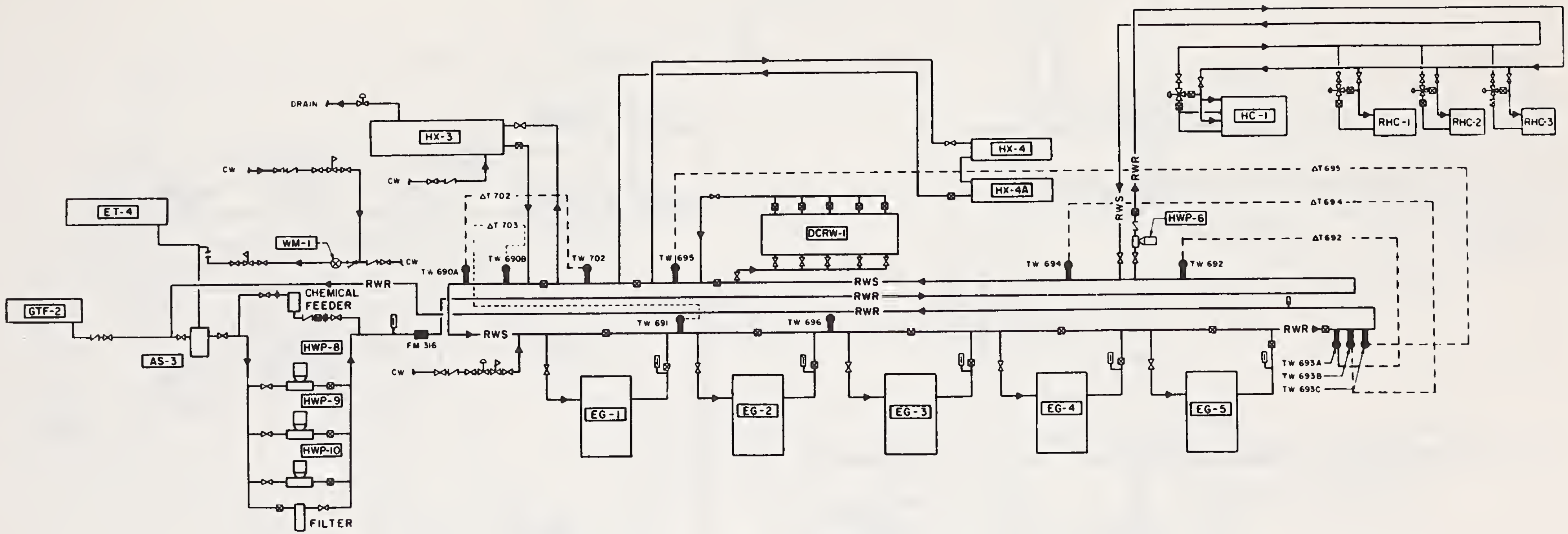
A1-4 Electrical distribution and NBS instrumentation locations in Business Building, the School and Pool.



A1-5 Electrical distribution and NBS instrumentation in Camci and Descon-Concordia. The Descon normal feeder divides outside of the building and feeds two segments of the building separately

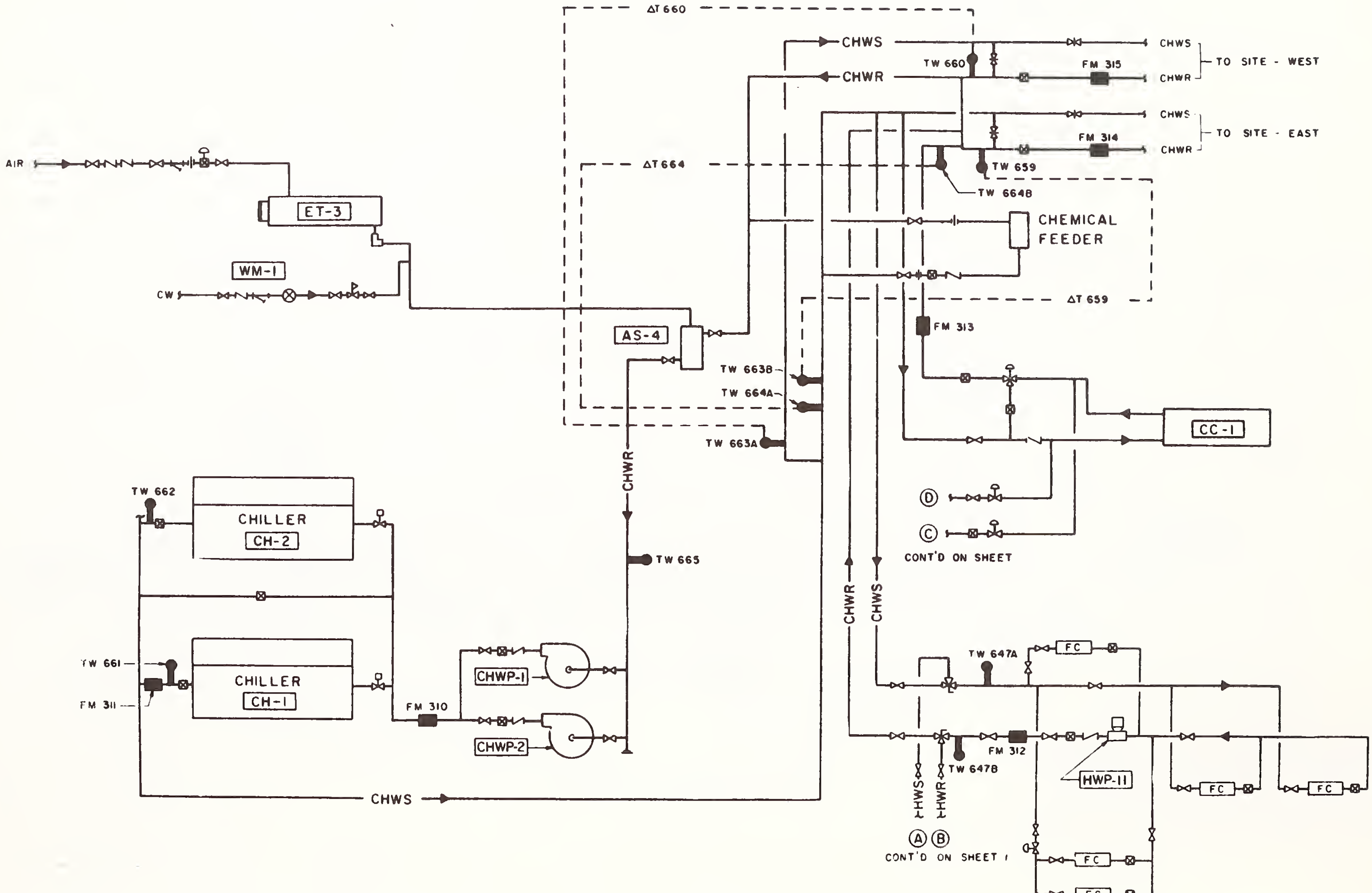


A1-6 Schematic of CEB primary hot water loop and NBS instrumentation locations.

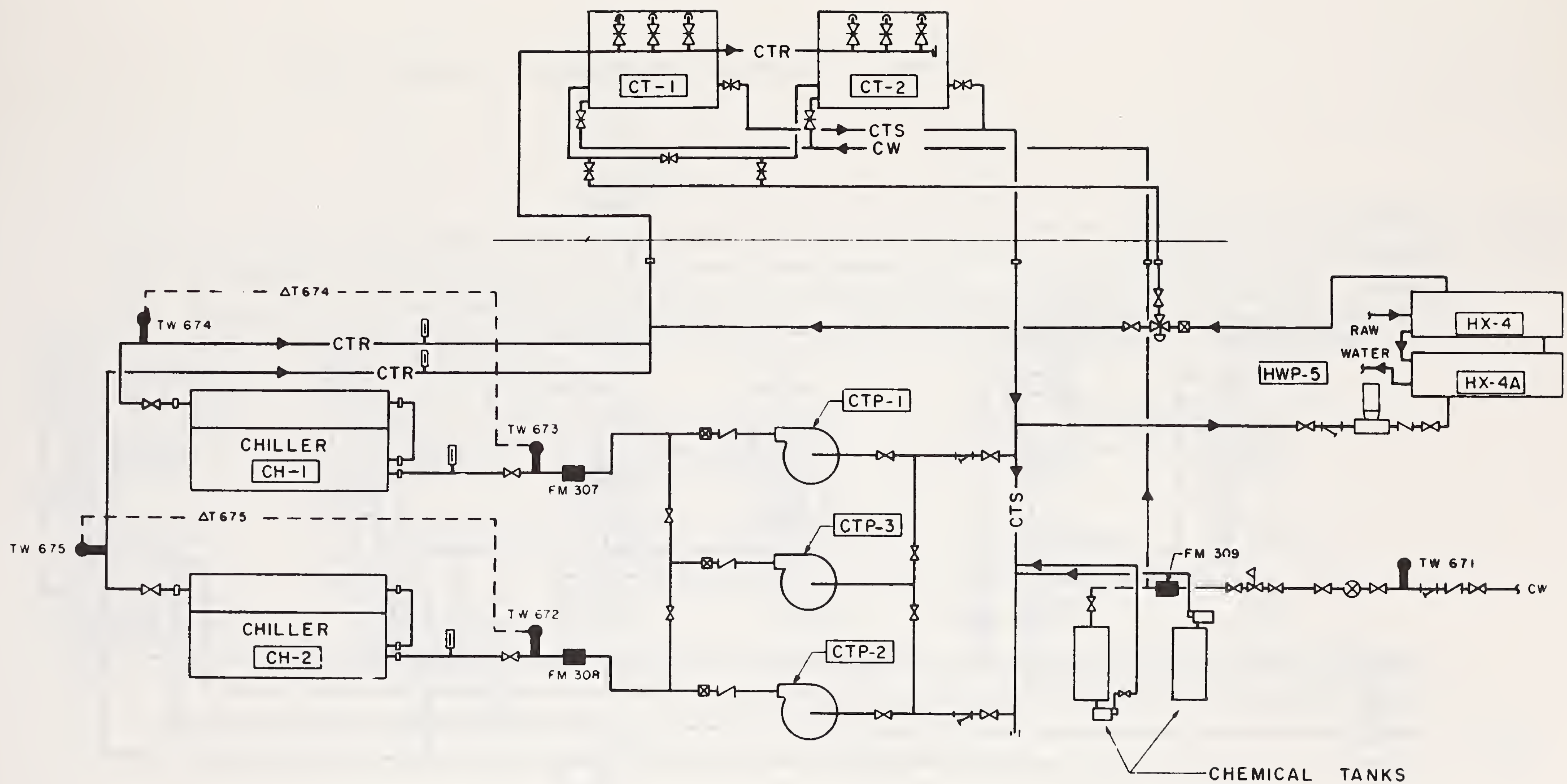


RAW WATER FLOW DIAGRAM

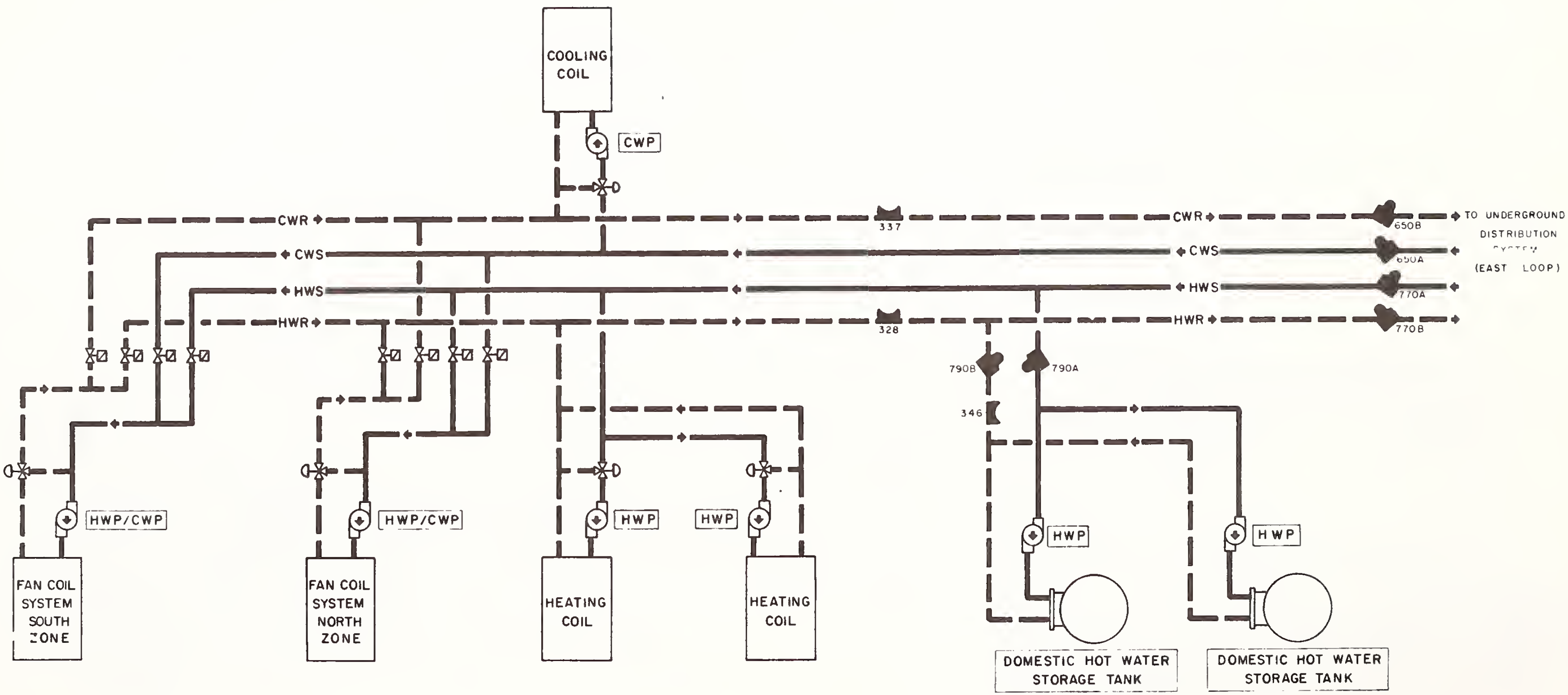
A1-7 Schematic of CEB raw water loop. Raw water flows through the engine oil coolers and aftercoolers.



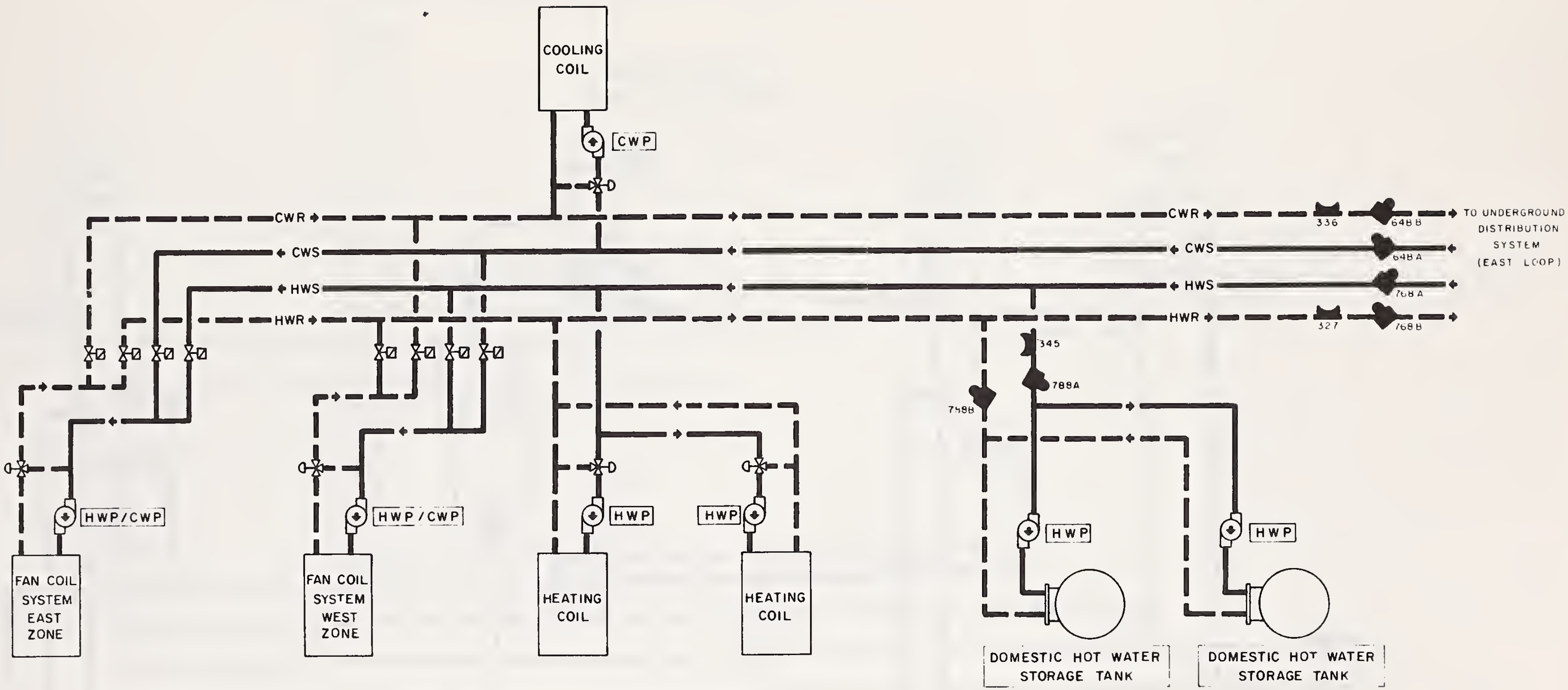
A1-8. CEB chilled water flow. "CC-1" is the main CEB cooling coil. "FCs" are CEB office fan coil units.



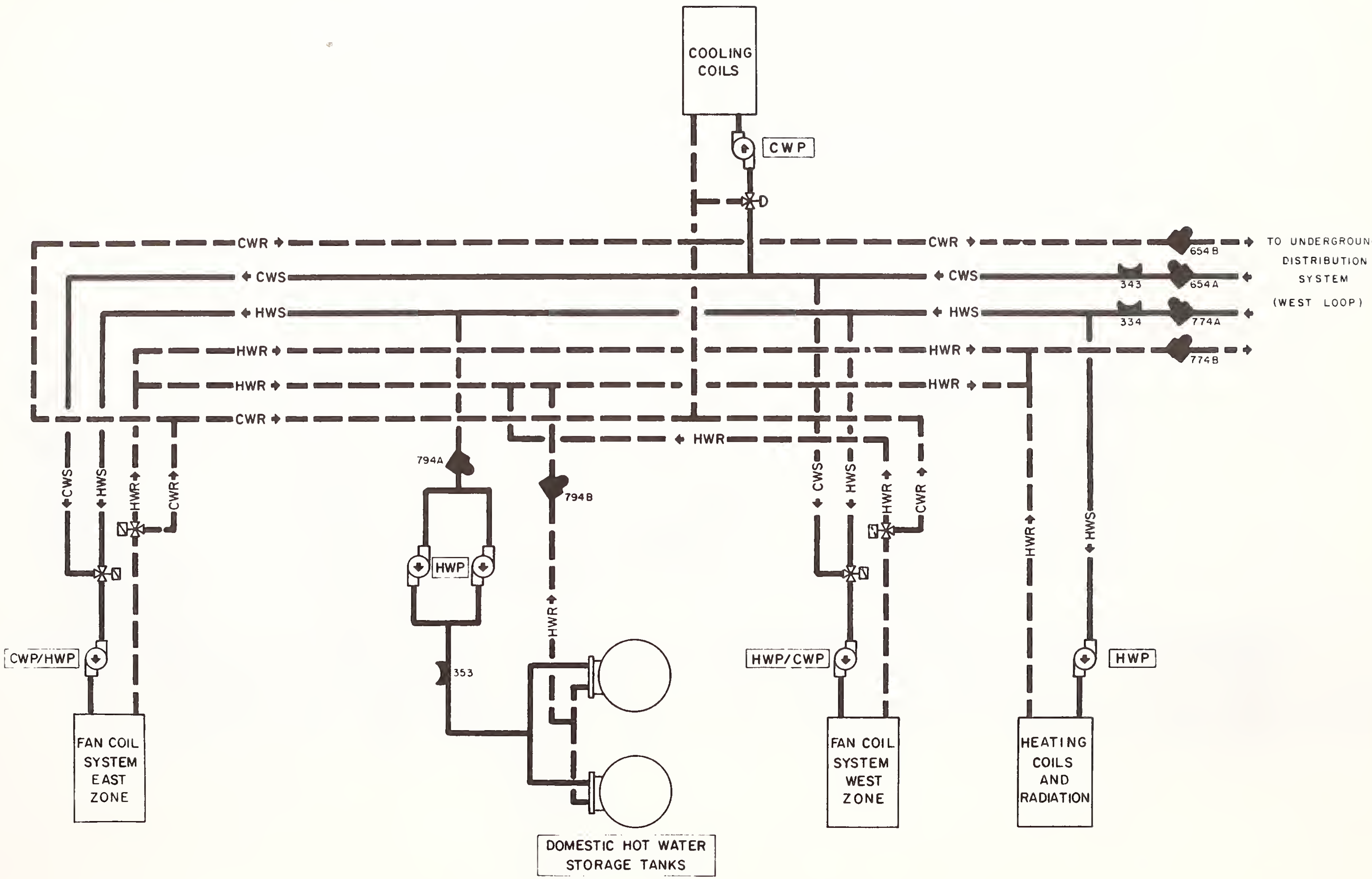
A1-9. CEB absorption chiller condenser water flow. CT-1 and 2 are roof mounted cooling towers.



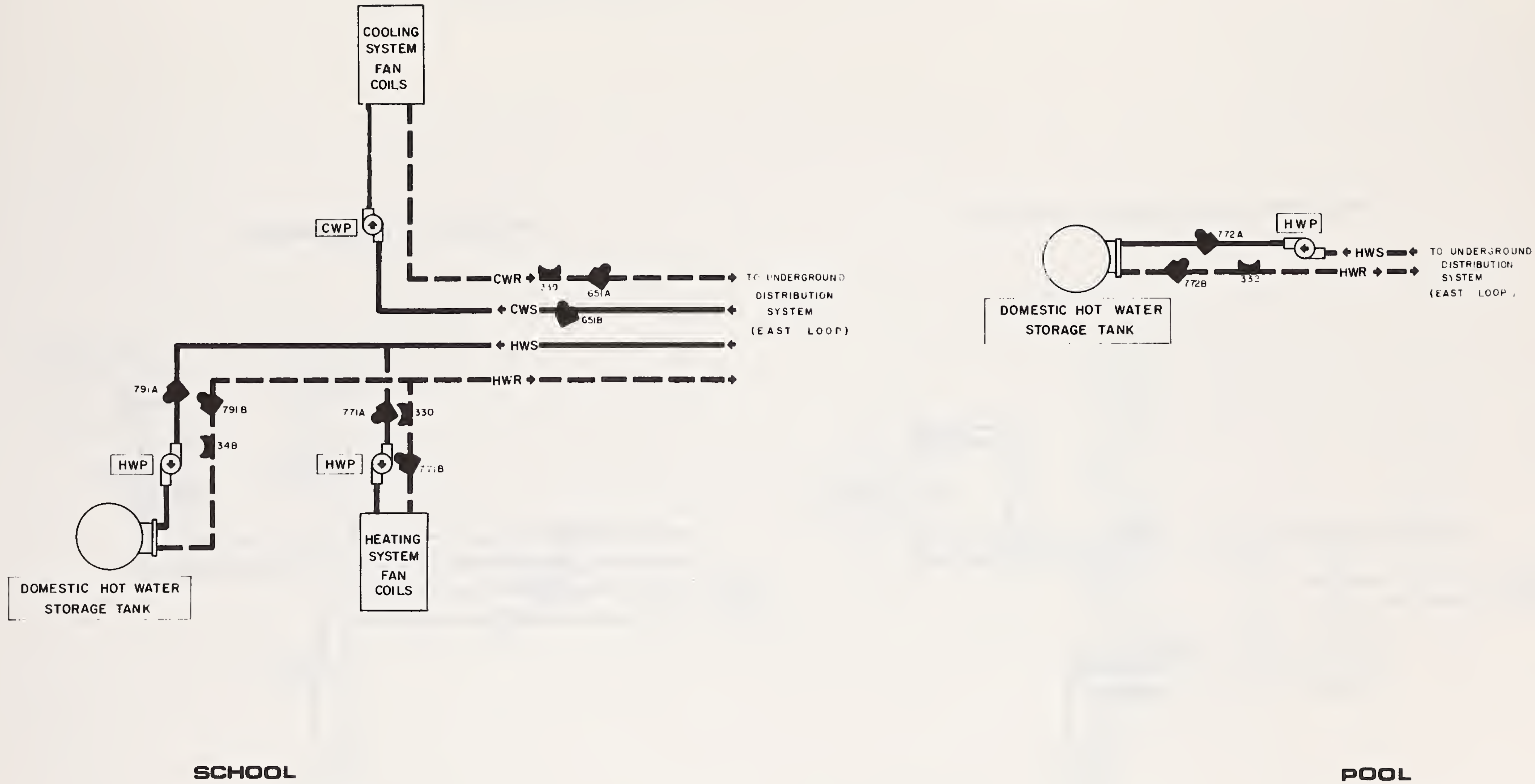
A1-10. Shelley B hot water and chilled water schematic.



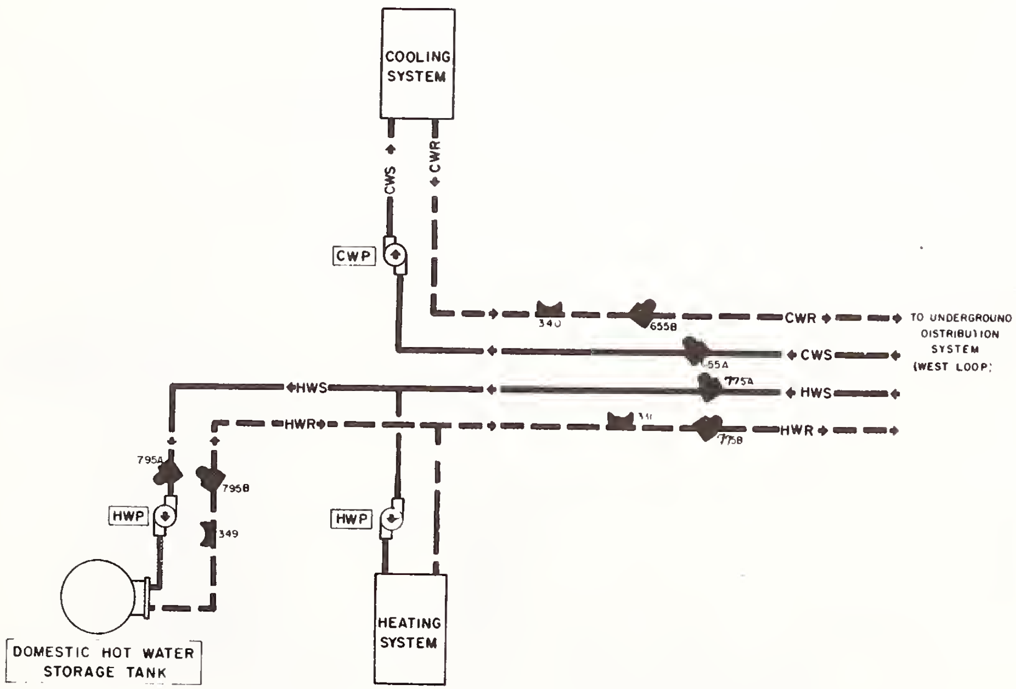
A1-11. Shelley A hot water and chilled water schematic.



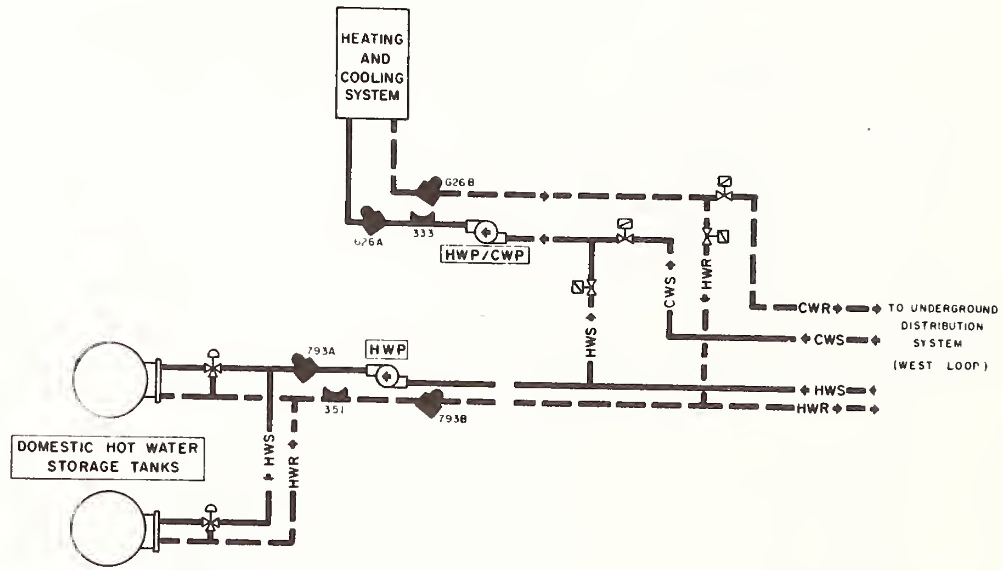
A1-12. Camci hot water and chilled water schematic.



A1-13. School and pool hot and chilled water schematics. The pool does not use chilled water.



- COMMERCIAL BUILDING -



- DESCON · CONCORDIA BUILDING -

A1-14. Commercial and Descon hot and chilled water schematics.

APPENDIX 2: Data Acquisition List:
A listing of all data channels by
channel number and NBS code number

National Bureau of Standards
Jersey City Total Energy System
Data Acquisition List

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
		SPECIAL CATEGORY	
HEADING	100	7 characters in the heading of each scan contain clock data: date (1-365) and time (0-24 hours plus minutes)	
172	102	Time generated by plant	5 minutes (2.82V/5 min)
173	110	Eng. run time EG 1	5 minutes (2.80V/5 min) when engine is on
174	111	Eng. run time EG 2	
177	130	Power factor on CEB bus	.5 lag - 1.0 (+5.0V - 0.0V)
178	141	Frequency of total plant output	59-61 Hz (0-5.0V)
		WEATHER STATION - Remote 005	
005-00	148	Direct solar radiation	Clear Sky (7.5V)
005-01	149	Indirect solar radiation	Bright Sky (1.6V)
008-08	150	Wind Direction	0-360 deg (0-3.6V)
008-09	151	Wind velocity	0-120 MPH (0-12V)
005-04	200	Outdoor baro. pressure	27-31 inches Hg (2.7 - 3.1V)
005-05	710	Outdoor temperature	-20° to 120°F (-2.0 to 12.0V DC)
005-06	712	Outdoor humidity	0 to 100% (0 to 10V DC)
005-07	714	Data cabinet ambient temperature	

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
		PRESSURE CATEGORY (#'s 200 to 299)	
010	202	CEB primary hot water system pressure, at pump outlet	0 to 100 psi transducer range (2-10V DC)
011	220	Lub. oil pressure EG-1	Normal Values: 202-55 psi (6.4V) 220,
012	221	Lub. oil pressure EG-2	221-50 psi (6.0V) when engine is on.
013	230	Exhaust gas back pressure EG-1	Transducer range 0-30 inches water (2-10V DC
014	231	Exhaust gas back pressure EG-2	Normal 20 in. (7.0V) when engine is on.
		FLOW CATEGORY (#'s 300 to 399)	
		All flows determined by Venturi and delta pressure transducer unless a turbine meter is specified. Delta pressure cells have 0 to 150" H_2O range (2-10V DC).	
015	301	Primary water flow to all engines	11,300 lb/min (6.1V)
016	302	Primary water flow from engine 1 jacket	2,200 lb/min (5.0V)
017	303	Primary water flow from eng. 2 jacket	2,300 lb/min (5.2V)
018	304	Primary water flow from Chiller #1	7,500 lb/min (5.1V)
019	305	SHW return from HSP East (Shelley A, Shelley B, School, Pool)	8,700 lb/min (6.3V)
020	306	SHW supply to HSP West (Business, Camci, Descon)	7,000 lb/min (8.2V)
021	307	Condenser water flow inlet to Chiller CH 1	14,000 lb/min (4.5V)
022	308	Condenser water inlet to Chiller #2	17,000 lb/min (5.9V)
023	309	Total condenser water makeup	
024	310	Total chilled water flow to both chillers	20,000 lb/min (5.5V)
025	311	Chilled water from chiller #1	10,000 lb/min (6.4V)
030	312	Chilled water or HWR ret. from plant fan coil units FC-1 thru 5 (Turbine)	

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
027	313	Chilled water return from main CEB air inlet coil CC-1	900 lb/min (4.1V)
028	314	Chilled water from HSP East zone	9,000 lb/min (5.5V)
029	315	Chilled water from HSP West zone	9,000 lb/min (3.2V)
026	316	Total raw water from all engines	3,200 lb/min (8.8V)

FUEL CONSUMPTION - DIRECT TURBINE MEASUREMENT

140	360	Engine 1	0-.6 GPM
141	361	Engine 2	0-.6 GPM
142	362	Engine 3	0-.6 GPM
143	363	Engine 4	0-.6 GPM
144	364	Engine 5	0-.6 GPM
145	365	Boiler 1	0-1.5 GPM
146	366	Boiler 2	0-1.5 GPM
147	367	Spare	0-10.24 VDC

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
		SITE BUILDING FLOW	
		Flow by venturi and delta pressure transducer unless a turbine is specified. All delta pressure cells range 0 to 150 inches water (2-10V DC).	
		CEB Secondary Hot Water to Buildings	
007-01	327	Shelley A Total Building Return	
006-01	328	Shelley B Heating Return	
003-01	330	School Heating Hot Water Return	
004-01	331	Business Building Total Building Return	
002-01	332	Pool Domestic Hot Water Exchanger Supply	
009-01	333	Descon Concordia Heating Hot Water in Winter, Chilled Water in Summer	
008-01	334	Camci Total Building Supply	
		CEB Chilled Water To Each Building	
007-03	336	Shelley A Return	
006-03	337	Shelley B Return	
003-03	339	School Return	
004-03	340	Business Building Return	
008-03	343	Camci Supply	
		CEB SHW To Building Domestic Heat Exchanger	
007-05	345	Shelley A Supply	
006-05	346	Shelley B Return	
003-05	348	School Return (turbine)	
004-05	349	Business Building Return (turbine meter)	
009-03	351	Descon Return	
008-05	353	Camci Supply	

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
		ELECTRICAL SIGNALS	
		Voltage (#'s 400 to 499)	
160	400	CBB main bus line voltage, ØA-B	480V AC (12.0V DC)
163	410	PSE&G feeder in CEB, utility side	480V AC (12.0V DC)
007-08	416	Shelley A PN5 voltage	480V AC (6.0V DC)
006-08	420	Shelley B PN4 voltage	120V AC (6.0V DC)
003-08	424	School PN3 voltage	277V AC (2.77V DC)
009-07	426	Descon-Concordia PN2 A3	480V AC (6.0V DC)
009-08	428	Descon-Concordia PN2 A1,2	120V AC (6.0V DC)
008-08	430	Camci PN1 voltage	480V AC (6.0V DC)
004-08	432	Business Bldg. PN1 voltage	277V AC (6.0V DC)
		Integrated Power (#'s 500 to 549)	
110	501	Total plant production	500-1300 kW
111	502	GEN #1 Production	200-450 kW
112	503	GEN #2 Production	200-450 kW
113	509	PTC Compactor Load	
114	510	LP-1	12-16 kW
115	511	MCC-1	100-150 kW
116	512	MCC-2	30-50 kW
117	513	MCC-3	150 kW in summer
118	514	PTC	
007-07	515	Shelley A PE2	30-40 kW
007-06	516	Shelley A PN5	180-350 kW
006-07	519	Shelley B PE2	10-20 kW
006-06	520	Shelley B PN4	40-110 kW
002-04	522	Pool PN3	
003-07	523	School PE3	
003-06	524	School PN3	
009-04	526	Descon-Concordia PN2, A3	40-100 kW
009-05	527	Descon-Concordia PE1, A3	40-45 kW
009-06	528	Descon-Concordia PN2, A1,2	50-150 kW
008-07	529	Camci PE1	30-40 kW
008-06	530	Camci PN1	100-200 kW
004-07	531	Business Bldg. PE1	
004-06	532	Business Bldg. PN1	

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
		Instantaneous Power	
		DC voltage proportional to KW (0-10V DC)	
041	550	Total Plant Production	700-1200 kW
042	551	Generator #1	200-350 kW
043	552	Generator #2	200-350 kW
044	553	PTC Compactor	
045	554	LP-1	18-21 kW
046	555	MCC-1	125 kW
047	556	MCC-2	38 kW
048	557	MCC-3	150 kW summer
049	558	PTC	

TEMPERATURE CATEGORY (#'s 600 to 799)

Actual temperature signals originate from a single thermocouple junction, delta (DT) measurements from a pair of multi-junction piles. Signal levels are -10 to +10 mV. All are type T copper-constantan unless otherwise noted.

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
050	600 A,B,C	(Actual) PHW temp. to all engines	175-195°F
086	601	(DT) PHW between engine 1 jacket water inlet & outlet (600C & 603)	3-6°F ON -1 OFF
087	602	(DT) PHW between engine 2 jacket water inlet & outlet (600B & 604)	3-6°F ON -1° OFF
051	603	(Actual) PHW outlet from EG-1 jacket	Inlet plus 3-6°F
052	604	(Actual) PHW outlet from EG-2 jacket	Inlet plus 3-6°F
089	605	(DT) PHW supply and return all engines (600A)	3.5-6.0°F
080	612	(Actual) exhaust gas temp. in boiler 1 stack, iron constantan	300-460°F ON 160°F OFF
081	613	(Actual) exhaust gas temp. in boiler 2 stack, iron constantan	300-460°F ON 160°F OFF
090	614	(DT) ~~PHW~~ across EG-1 jacket plus M-1 (600A)	4.5-7.0 ON
091	615	(DT) PHW across EG-2 jacket plus M-2 (600C)	4.5-7.0 ON

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in parentheses
053	616	(Actual) PHW outlet from M-1	195-215°F
054	617	(Actual) PHW outlet from M-2	195-215°F
055	627 A,B,C	(Actual) PHW outlet of both boilers, inlet to the chillers.	195-225°F
092	628	(DT) PHW across B-2 inlet & outlet (627C)	-1 to 14°F
056	629	(Actual) PHW inlet to HX-1, 1-A, outlet of chillers	170-195°F
057	630	(Actual) PHW inlet to DCJW, outlet of HX-1, 1A	165-195°F
093	631	(DT) in PHW main line caused by DCJW (630)	.3-1.0°F
094	632	(DT) PHW across inlet & outlet of HX-1, 1A (629&630)	10-18°F winter
058	633	(Actual) PHW inlet to boilers	170-195°F
095	634	(DT) PHW across inlet & outlet, CH-1 (627B)	8-20°F
096	635		
059	636	(Actual) PHW outlet of DCJW (uses well 631)	170-185°F
097	637	(DT) PHW across inlet & outlet of both boilers (633 & 627A)	5-15°F
060	640	(Actual) mixed outlet of both SHW heat exchangers, SHW to site.	175-190°F
098	641	(DT) across East site SHW supply & return (640)	7-15°F winter
099	642	(DT) across west site SHW supply & return (640)	12-21°F winter
100	647 A,B	(DT) CHW or HW across CEB office fan coil supply & return	
101	659	(DT) across East site CHW supply and return	1-5°F
102	660	(DT) across West site CHW supply and return	1-5°F

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in Parentheses
061	661	(Actual) CHW outlet CH-1	42-50°F
062	662	(Actual) CHW outlet CH-2	42-50°F
063	663 A,B	(Actual) temp. chilled water to site West zone	42-50°F
103	664 A,B	(DT)across CC-1 supply & return	
064	665	(Actual) CHW to inlet of both chillers.	45-55°F
065	671	(Actual) condenser water makeup	65-75°F
066	672	(Actual) condenser water inlet to CH-2	75-85°F
067	673	(Actual) condenser water inlet to CH-1	75-85°F
104	674	(DT) condenser water temp between inlet & outlet CH-1 (673)	2-12°F
105	675	(DT) condenser water temp. between inlet & outlet CH-2 (672)	2-12°F
068A	690 A,B	(Actual) raw water inlet to all engines	70-85°F
069	691	(Actual) raw water supply manifold after E-1 outlet, before E-2 inlet.	70-85°F
106	692	(DT) between inlet and outlet of raw water pumps. (693A)	-.2°F
070	693 A,B,C	(Actual) raw water temp. downstream of all engines--total engine outlet	75-85°F
088	694	(DT) RW across HWPS and HC-1 plus RHC-1 thru 3 (693B)	.2°F
107	695	(DT) RW between total engine outlet and DCRW outlet (693C)	6-8°F
071	696	(Actual) Raw water supply manifold after E-2 outlet, before E-3 inlet.	70-80°F
072	700	(Actual) lub. oil sump Eng. 1	120°F OFF, 180°F ON
073	701	(Actual) lub. oil sump Eng. 2	120°F OFF, 180°F ON

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in Parentheses
108	702	(DT) RW across HX-3 (690A)	
109	703	(DT) on RW supply manifold across E-1 (691 & 690B)	1.5°F ON
074	711	(Actual) engine room air temp. db	75-85°F
075	713	(Actual) engine room air temp. wb	60-75°F
076	730	(Actual) fuel oil supply to all engines	84-93°F
077	731	(Actual) fuel oil return from all engines	85-94°F
078	732	(Actual) fuel oil supply to boilers	70-81°F
079	733	(Actual) fuel oil return from boilers	71-82°F
082	750	(Actual) temp. of exhaust gas entering M-1, iron constantan	480-600°F ON 130°F OFF
083	751	(Actual) temp. of exhaust gas entering M-2, iron constantan	480-600°F ON 130°F OFF
084	752	(Actual) temp. of exhaust gas leaving M-1, iron constantan	400-500 ON 130°F OFF
085	753	(Actual) temp. of exhaust gas leaving M-2, iron constantan	400-500°F ON

WATER TEMPERATURES AT SITE BUILDINGS

(Actual) Chilled Water To Individual Buildings

006-09	643	Shelley B (well 650A)	42-50°F for all buildings
007-10	644	Shelley A (well 648A)	
008-10	645	Camci (well 654A)	
009-09	646	(Actual) Hot or chilled water for heating or cooling (well 626A)	
003-09	624	School	
004-10	625	Business Building	

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in Parentheses
		(DT) Chilled Water Between Building Supply And Return Well A is Supply, B Return	
007-02	648	Shelley A	
006-02	650	Shelley B	
003-02	651	School	
009-00	626	Descon Heating and Cooling	
008-02	654	Camci	
004-02	655	Business Building	
		(Actual) CEB SHW To Buildings	
002-08	760	Pool domestic	170-190°F for all buildings
003-10	761	School heating supply	
004-11	762	Business Bldg. Total Bldg. supply	
006-10	763	Shelley B Total Supply	
007-11	764	Shelley A Total bldg. supply (uses well 768)	
008-11	765	Camci Total bldg supply (uses well 774)	
		(DT) Between HWS and HWR	
007-00	768	Shelley A total building	
006-00	770	Shelley B total building	
003-00	771	School heating	
002-00	772	Pool domestic	
008-00	774	Camci total bldg.	
004-00	775	Business bldg. total bldg.	
		(Actual) HW Temperature Inlet To Domestic Heat Exchanger	
003-11	781	School	170-190°F for all buildings
004-12	782	Business bldg.	
006-11	783	Shelley B	
007-12	784	Shelley A	
008-12	785	Camci	
009-10	786	Descon-Concordia	
		(DT) Hot Water Inlet and Outlet of Domestic Heat Exchanger	
007-04	788	Shelley A	
006-04	790	Shelley B	
003-04	791	School	
009-02	793	Descon-Concordia	
008-04	794	Camci	
004-04	795	Business bldg.	

DAS CHANNEL	NBS CODE	Identification	Normal Physical Range DAS mV in Parentheses
		ALARMS AND INDICATORS (#'s 800 to 899)	
	Engines		
127	800	Engine low oil pressure, malfunction	Engine 1 -(2.58V)
	801	Engine high water temperature, malfunction	(1.29V)
	802	Engine high oil temperature, malfunction	(.65V)
	803	Engine overspeed (110%)	(.32V)
	804	Engine underspeed (90%)	(.16V)
	805	Engine excessive vibration malfunction	(.08V)
120	806	Engine high oil coolant temperature	Engine 1 -(2.58V)
	807	Circuit breaker trip	(1.29V)
	808	Engine excessive start time	(.65V)
	809	Generator overload	(.32V)
	810	Failure to parallel	(.16V)
	811	Reverse power protection	(.08V)
121	815 to 820	(Same as 800 to 805)	Engine 2
122	821 to 826	(Same as 806 to 811)	Engine 2
123	830 to 835	(Same as 800 to 805)	Engine 3
124	836 to 841	(Same as 806 to 811)	Engine 3
125	845 to 850	(Same as 800 to 805)	Engine 4
126	851 to 856	(Same as 806 to 811)	Engine 4
128	860 to 865	(Same as 800 to 805)	Engine 5
129	866 to 871	(Same as 806 to 811)	Engine 5

APPENDIX 3: Specifications for the NBS Data Acquisition System

SPECIFICATION FOR THE NBS DATA ACQUISITION SYSTEM NO. 2672

I. GENERAL

A. Site Description

The data acquisition system described herein will be used to collect data on energy use and total energy plant operations on the Jersey City Operation BREAKTHROUGH site. This site includes a total energy plant which serves a residential complex of four medium to high-rise apartment buildings, two schools, about 5000 sq. ft. of light commercial space, and a swimming pool. Overall site dimensions are approximately 1400 ft. b6 700 ft. (See Appendix A for site layout.)

The total energy plant is built around five 600 kilowatt diesel generators which produce all the electricity for the site. The heat from the cooling water and exhaust gases of the diesel generators is used to heat, air condition (utilizing absorption chillers), and provide domestic hot water for the site buildings. Supplemental heat for these uses is produced by two 400 horsepower hot water boilers. Chilled water is produced by two 526-ton absorption chillers.

The electricity, chilled water, and hot water are generated in the Central Equipment Building (CEB) which is located in the center of the site. All services are distributed from the CEB to other site buildings in underground conduits. Electricity is generated and distributed at 480 volts, three phase, sixty hertz, three wire delta. In each building the 480 volts are transformed down to 208/120 four wire wye.

Chilled water is pumped from the CEB to each building except the pool. The chilled water leaves the CEB at 44°F and returns at 58°F. In each building, booster pumps distribute the chilled water throughout the building.

Hot water is generated through a closed heat exchanger with the jacket water from the diesels. The hot water is pumped to each building on the site. The hot water leaves the CEB at 200°F and returns at 180°F. In each building, booster pumps distribute the hot water for space heating and for domestic hot water generation.

B. Data Acquisition System

The Data Acquisition System (DAS) which is further defined herein is to be used to collect and record, on computer-compatible magnetic tape, energy use and related data from government-supplied measurement devices located in the CEB and all other site buildings. Appendix B is a complete list of the inputs to the DAS. Typical measurements in

the CEB are the following: on two of the diesel engine generators - watt-hours, frequency, power factor, fuel flow, engine cooling water flow and temperature, heat recovery muffler water temperature and exhaust gas temperature; on all engine-generators - all alarm signals; alarm signals from the site's pneumatic trash handling system; weather data; and time and date.

Appendix C shows schematically the data that will be collected from each remote building. Typical data in a building are as follows: watt-hours on the normal and essential load feeders, secondary voltage (208) on each feeder, chilled water flow from the building, chilled water return and differential temperatures, hot water flow from the building, return and differential hot water temperatures, hot water from the domestic hot water heaters, return and differential domestic heating hot water temperatures.

C. Site Conditions

All wire or cable runs between remote buildings or to the CEB must be made in a government provided instrumentation raceway and in a government provided non-ferrous conduit which is located approximately 2 feet from and in parallel with the site electrical distribution system; said system being 480 volts, 60 cycles, 3 phase, with ampere loadings as referenced in Appendix A.

II. DATA ACQUISITION SYSTEM REQUIREMENTS

This specification describes the minimum requirements necessary for the DAS to accomplish the end result of providing data from all measurements on magnetic tape in a computer-compatible format convenient for subsequent analysis and evaluation.

All systems or system manufacturers must meet or exceed the following or equivalent requirements.

A. Number of Channels

1. Equipment located in the CEB shall monitor and record data from all 300 individual channels-approximately 170 of which are located in the CEB, the balance in the other site buildings. The system must be expandable to monitor a total of 1000 channels. (See Appendix B.)

2. Equipment in each of the remotely located buildings must convert data on 13 channels from low level signals (see II.D.2) to 0 to 5 volts or to digital signals for interference-free transmission over distances of up to 1000 ft. to the central monitoring and recording equipment in the CEB. This equipment must be expandable to 30 channels per building without adding to the inter-building wiring.

B. System Scan & Interrogation

1. Equipment located in CEB shall scan all measurement channels continuously, including those which are input from the remote buildings. System scan rate shall be a minimum of 20 readings per second.

2. The system shall have the capability of operator (front panel) or automatic selection (relay) of single, repetitive, or continuous scan (interrogation) modes. The single scan mode will cause a single interrogation of all system channels and will record the beginning time of scan and the data from each channel. The repetitive interrogation mode will cause the single interrogation mode to be executed at the end of each time period as described in Section C. The continuous interrogation mode will cause a series of single interrogation modes to be executed at the fastest possible rate and will continue to be repeated until the cause of the automatic continuous mode selection is removed or until operator intervention. If the continuous/single mode selection is made through automatic external means when such is removed, the system shall return automatically to the mode of operation in which it was in at the time just prior to the automatic continuous/single mode selection.

3. Channel selection will be 000-999 for the first channel and 000-999 for the last channel, front panel controlled.

C. Clocking

1. Provision shall be made to allow operator to select the channel interrogation rate. This rate control shall make it possible to select any time interval from five minutes to two hours. This time selection shall cause all channels to be interrogated repetitively at the end of each such time interval, and the data from each to be recorded.

2. System shall include an internal clock so that the day, hour, and minute is recorded along with the data from every channel on each scan. The clock shall visually display days, hours, minutes and seconds with an accuracy of $\pm$ 2 x 10^{-6} seconds and with a drift of 1 ppm/week. The clock shall be battery-backed to provide 4 hours operation in the event of power failure.

D. System Input

1. System shall have the following electrical accuracy and electrical noise rejection capabilities when operating as an installed or completed system subject to external site influences:

a. Transducer to recording device accuracy of .1% of full scale for any input from 1 millivolt full scale to 1000 volts full scale. The following are considered necessary to achieve this accuracy:

(1) Transducer to first active device common mode noise rejection (CMR) of 120 db; and a common mode voltage rejection of up to 300 volts.

(2) Transducer to first active device normal mode noise rejection (NMR) of 48 db minimum when the system is operating at a scan rate of 20 readings per second. If provision is made for an optional slower scan rate, normal mode rejection at the slower scan rate shall be no less than 100 db from the transducer to the first active device.

(3) Analog to digital converter shall have a minimum of 120 db CMR and 140 db CMR with a filter.

b. Block diagrams of typical government-provided transducers which provide input signals to the DAS are included as Appendix D.

2. Outputs from the government-provided transducers consist of the following:

Approximate Number of Channels	Output Signal
48	0 to 1 millivolt
50	0 to 100 millivolt
43	0 to 1 volt
70	0 to 5 volt
33	4 to 20 milliamps
up to 20	Switch closures Switch openings

E. Output

1. The data recording device shall have the following capabilities when installed and operating in the system:

a. Recording device shall be a reel type, 7 or 9 track, 800 bits per inch maximum, synchronous or incremental, Univac 1108 computer compatible on magnetic tape; and shall be able to accept without modification a minimum standard magnetic tape reel size of 2400 feet.

b. Recording device shall be capable of recording a minimum of 4 days of data on a single tape reel which includes the time (days, hours, minutes), channel identification number, and channel data from scans repeated every five minutes with each scan consisting of up to 300 measurement channels.

c. Provision shall be made for entering manual header information consisting of a minimum of six characters on the magnetic tape. This information shall be enterable at appropriate times without interrupting system scan.

d. Tape recorder must be capable of generating inter-record gaps of a length which may vary from 1 to 999 characters.

e. Information as recorded on the magnetic tape shall include parity.

2. Equipment located at the CEB shall have the capability of visually displaying the data from any desired single channel including those being input from the remote buildings by manual selection of the channel identification from the equipment panel, without interfering with the scan speed. This displayed data shall be self-updating at a speed no faster than the ability of the eye to read.

3. Contact closure, upon system shutdown.

F. Computer Control

The data recording system shall have the future expansion capability for addition of an on-site computer for system control and data analysis. This is not to say that the system described here shall be a computer, but rather that the system described shall be computer compatible.

G. Desirable Options (Add-On)

The data recording system shall have the specific peripheral attachment options as follows:

a. High speed printer
b. C.R.T. display
c. Emergency power supply
d. Teletype and paper punch which does not slow down the system.

The items listed above are not to be included in the basic data acquisition system; however, the system shall be so configured as to permit add-on of the items listed at the option of the government at any time.

H. Racks

The entire data acquisition system, including the remotely located equipment, shall be furnished completely installed in first quality, tamper proof racks or cabinets. These cabinets or racks shall be of such a design that access, via hand operated locked latches on hinged doors, to all equipment contained therein may be made easily by authorized personnel within a time duration not in excess of two seconds. Equipment cabinets or racks shall be burr free, contain no sharp edges, and be painted consistent with the installation surroundings.

I. Installation

The manufacturer shall, in addition to delivering the equipment described above, be responsible for the following:

1. Provide for and supervise the electrical installation of government supplied transducers and associated transducer power supplies. The government will supply all transducers (approximately 300) and transducer power supplies; and make certain that proper provisions have been made for the mechanical installation of the transducers.

2. Provide for and supervise the electrical connection of all transducers to the data acquisition system. Transducers are a 3-wire output type and, in some cases, will require input power connections. The government will supply all transducer connection wire and transducer end connectors. The manufacturer will supply all mating connectors for the data acquisition system. Government provided transducers include the following:

Use	Type	Input Power	Approx. Number
KWH	Hall effect	AC	27
Fuel	Turbine	AC	10
Heat Transfer	Venturi	DC	37
Temperature	Thermocouple	-	105
Alarm	Digital	DC	90 (combines to 12 analog outputs)
Pressures	D.P Cell	DC	8
Weather Data	-	AC	5
Misc.	-	-	50

3. Provide for and supervise the connection of all components of the data acquisition system as supplied by the manufacturer. The government is providing twisted pair shielded wire. If a vendor wishes to use other wire, such bids should include cost of wire. The manufacturer will furnish all necessary connectors, distribution panels, and miscellaneous items necessary to perform this function. All connectors will be terminated in a neat and orderly fashion such that spare wires, cables, data channel wires, and other required wires are readily identified and usable.

4. Assume complete responsibility for the correct identification hookup, and end-to-end operation of the entire data collection system, exclusive only of the transducer outputs at the point of egress from the transducers.

5. Furnish all electrical or electronic equipment necessary to allow for proper data entry into the data acquisition system, and any recording of said data.

J. <u>Warranty</u>

1. Performance of the system for acceptance by the government will be determined by its response in all modes of operation.

2. The warranty period shall begin after government acceptance of the system as described above and shall continue for a period of not less than 1 year. The warranty shall cover all service, maintenance,

labor, parts, and miscellaneous items which may from time to time become defective or cause a system failure or partial failure.

3. Service shall be provided during the warranty period and spare parts shall be maintained by the equipment manufacturer such that arrival of service personnel shall not exceed 5 hours and that delivery time of spare parts shall not exceed 12 hours. In no event can the government tolerate a single down time of the system of greater than 12 hours or an accumulated weekly down time in excess of 12 hours. Accumulated yearly down time shall not exceed 7 days. It is anticipated that the system will be in operation unattended 24 hours a day continuous in excess of 2 years. Service shall include preventive maintenance checks in accordance with recommended procedures and shall be provided within one or two weeks before Christmas and Thanksgiving.

4. Provision shall be made for an extension of the warranty for additional two (2) year periods.

K. Training

Furnish training and schooling of operating personnel in the proper operation, technical principles, trouble shooting for minor repairs, and maintenance of all manufacturer furnished equipment. It is anticipated that approximately six personnel will require such training. Proposals shall include number of hours needed for schooling.

L. Drawings and Specifications

Respondees shall provide complete technical specifications and descriptions of equipment offered and shall also provide operation and maintenance manuals and spare parts listings.

M. Capability

Any proposed manufacturer must demonstrate that his particular company has built and serviced similar systems for two years and that a system similar to that offered has been in continuous operation for a time period sufficiently long (one year minimum) to indicate to the satisfaction of the purchaser that the equipment will in fact perform satisfactorily and reliably.

Attachments

The attached drawings and tables form a part of this specification and must be considered with respect to all offers concerning the described data acquisition and recording system and associated labor and responsibilities.

DER/LDB/JES
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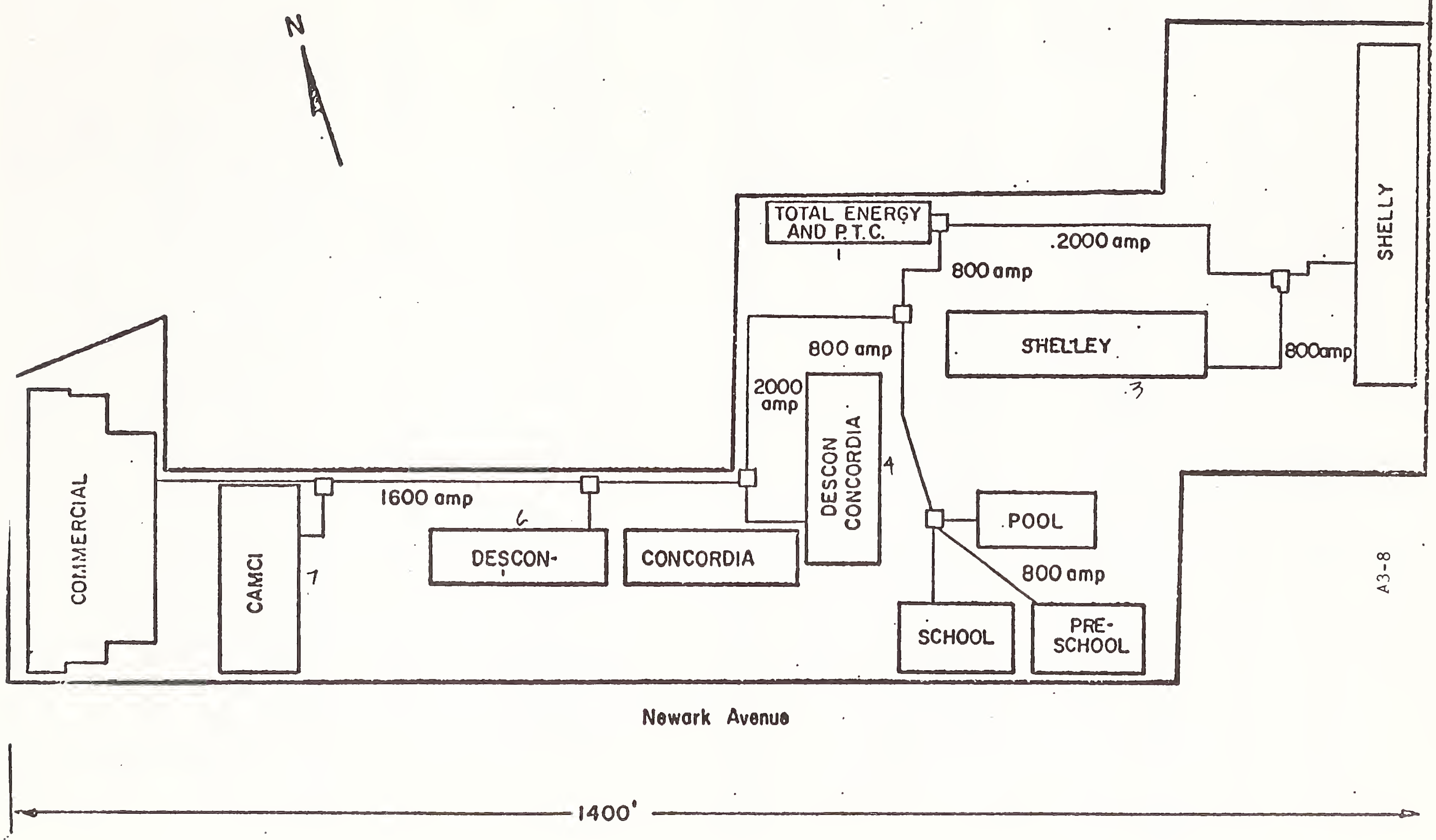
Appendix A

JERSEY CITY BREAKTHROUGH SITE

TOTAL ENERGY DATA ACQUISITION SYSTEM

LOCATION OF COMMUNICATION DUCTS AND ELECTRICAL LOADING



Appendix B

National Bureau of Standards
TOTAL ENERGY SYSTEM
Data Acquisition List

NBS Code Number	Identification	
	Special Category (time, pf, Hz, wind, #'s 100 to 199)	
100	Time (standard)	00:00:00 to 24:00:00
101	Date	1 to 365
102	Time generated by plant	
110	Eng. run time EG 1	
111	Eng. run time EG 2	
120	Eng. speed EG 1	
121	Eng. speed EG 2	
130	pf on individual generator G-1	
131	pf on individual generator G-2	
141	Frequency of total plant output	
147	Descon-Concordia valve setting, winter or summer	
148	Direct solar radiation	
149	Indirect solar radiation	
150	Wind direction	
151	Wind velocity	
	Pressure Category (#'s 200 to 299)	
200	Baro. press. ambient	
202	Press. of system water near boiler (pump discharge)	
220	Lub. oil pressure individual eng.	
221	" " " " " "	
230	Exhaust gas back pressure individual engine	
231	" " " " " "	
240	Chiller vacuum CH-1	
241	" " CH-2	

Flow Category (#'s 300 to 399)

301	Primary water flow return to all engines	
302	" " " from engine 1 jacket	
303	" " " " " 2 "	
304	" " " " chiller No. 1	
305	SHW flow return from HSP East	
306	" " " " " West	
307	Condenser water flow inlet to chiller CH 1 (CTS)	
308	" " " " " " CH 2 (CTS)	
309	Total condenser water makeup (CTS)	
310	Total chilled water flow to both chillers	
311	Chilled water from chiller CH 1	
312	" " or HWR ret. from plant air temp.coils (FC-1 to FC-5	
313	" " return from fan coil unit CC-1	
314	" " from HSP East zone	
315	" " " " West "	
316	Total raw water to all engines	
317	Fuel flow to boiler 1	(turbine meter)
318	" " from boiler 1	" "
319	" " to boiler 2	" "
320	" " from boiler 2	" "
321	" " to all engines total (FOS)	" "
322	" " from all engines total (FOR)	" "
323	" " to individual engine 1	" "
324	" " from individual engine 1	" "
325	" " to individual engine 2	" "
326	" " from individual engine 2	" "

(Total sec. HW flow, heating hot water at each bldg)

327	Shelley A (east)
328	Shelley B
329	Pre School
330	School
331	Commercial
332	Pool
333	Descon Concordia - Flow to Bldg A3-A1 CHWS and HWS
334	Camci

(Chilled water on each building line)

336	Shelley A
337	Shelley B
338	Pre School
339	School
340	Commercial
343	Camci

(Flow, domestic hot water generation in buildings)

345	Shelley A	
346	Shelley B	
347	Pre School	(turbine meter)
348	School	" "
349	Commercial	" "
350	Pool	" "
351	Descon	
353	Camci	

Electrical (voltage) (#'s 400 to 449)

400	Voltage, plant bus
410	" PSE&G bus
415	Volt, PE2 Shelley A (essential)
416	" PN5 " " (normal)
417	" PE2 Preschool
418	" PN4 "
419	" PE2 Shelley B
420	" PN4 " "
421	" PN2 Pool
422	" PN3 "
423	" PE2 School
424	" PN3 "
426	" PN2 East Descon-Concordia
427	" PE1 " " "
428	" PN2 West " "
429	" PE1 Camci
430	" PN1 "
431	" PE1 Commercial
432	" PN1 "

Watt (#'s 500 to 549)

500	KW total plant production
501	KW total plant production
502	KW GEN #1
503	KW GEN #2
509	KW used by PTC compactor
510	KW used by LP-1
511	KW used by MCC-1
512	KW used by MCC-2
513	KW used by MCC-3
514	KW PTC
515	KW PE2, Shelley A (east)
516	KW PN5, Shelley A (east)
517	KW PE2, Preschool
518	KW PN4, Preschool
519	KW PE2, Shelley B
520	KW PN4, Shelley B

522	KW PN3 Pool
523	KW PE2 School
524	KW PN3 School
525	KW PE2 Pool
526	KW PN2 East Descon-Concordia, A3
527	KW PE1 " " " A3
528	KW PN2 West Descon-Concordia, A1
529	KW PE1 Camci
530	KW PN1 "
531	KW PE1 Commercial
532	KW PN1 "

Temperature Category (#'s 600 to 799)

(Actual) means one T.C. reading, real. temp.
(ΔT) means differential temp.

600A	(Actual) PHW temp. to all engines
600B	
600C	
601	(ΔT) jacket water inlet & outlet engine (EG-1) (600 & 603)
602	(ΔT) " " " " " " (EG-2) (600 & 604)
603	(Actual) PHW outlet from engine EG-1
604	(Actual) " " " " EG-2
605	(ΔT) PHW supply and return all engines (600A)
612	(Actual) exhaust gas temp., boiler (B-1)
613	(Actual) " " " " (B-2)
614	(ΔT) PHWR across EG-1 & M-1 (600 B)
615	(ΔT) " " EG-2 & M-2 (600C)
616	(Actual) temp. PHW outlet from muffler (M-1, EG-1)
617	(Actual) " " " " " (M-2, EG-2)
626A	(ΔT) water temp. to and from Descon A3-A1 heating & cooling
626B	
627A	(Actual) PHWS total from boilers & inlet chillers
627B	
627C	
628A	(ΔT) PHWS between boilers & total from boilers (628B)
628B	
629	(Actual) PHWS temp. prior to HX-1, HX-2 inlet abs.
630	(Actual) temp. to dry coolers
631	(ΔT) HWR from dry coolers and to dry coolers (630)
632	(ΔT) temp. outlet coil & inlet to coil HX-1 (629) & (630)
633	(Actual) temp. PHW inlet to boilers
634	(ΔT) HWR & inlet to chillers (627B)
635	(ΔT) from outlet DCJ-1 & 2, and to 600B
636	(Actual) temp. on return line from dry coolers (uses well 631)
637	(ΔT) temp. inlet to boilers & from boilers (TW#'s 633 to 627A)
640	(Actual) temp. supply secondary HW coil (on primary line before E-W split)
641	(ΔT) return secondary HW coil & supply (640), East zone
642	(ΔT) " " " " " " West zone

	(Actual) CWS to individual buildings
644	Shelley A (east bldg)
645	Camci
646	(Actual) temp. supply in Descon pump room near F333 (uses well 626
647A	(ΔT) from TE plant air tempering coils & supply SHW coil FC-1 to F
647B	
	(ΔT) CWS from building supply & CWR building return
648	A&B Shelley A (east bldg)
649	A&B Preschool
650	A&B Shelley B
651	A&B School
654	A&B Camci
655	A&B Commercial
658	Reference number for TW at end of ΔT's
659	(ΔT) chilled water return from site and to East zone (663B)
660	(ΔT) " " " " " " " West zone (663A)
661	(Actual) chilled water chiller CH-1 to site
662	(Actual) " " " CH-2 to site
663A	(Actual) temp. chilled water to site West zone
663B	
664A	(ΔT) chilled water from air tempering coil CC-1 & to site
664B	
665	(Actual) CHWR to CH-1 & CH-2 after AS-4
671	(Actual) condenser water temp. makeup
672	(Actual) " " " inlet absorber CH-2
673	(Actual) " " " " " CH-1
674	(ΔT) condenser water temp. between inlet & outlet absorb. CH-1(w/
675	(ΔT) " " " " " " " CH-2(w/
690A	(Actual) temp. raw water coolant inlet to engines
690B	
691	(Actual) temp. raw water coolant on line between 2 eng. EG-1 & 2
692	(ΔT) raw water coolant in heating and after pumps (693A)
693A	(Actual) temp. raw water between pumps and engines
693B	
693C	
694	(ΔT) raw water from engines and to DCRW inlet (693B on main line
695	(ΔT) w/693C and on line after DCRW-1 & 2
696	(Actual) temp. raw water coolant on primary line between EG-2 &
700	(Actual) lub. oil, individual eng. 1
701	(Actual) lub. oil, individual eng. 2
702	(ΔT) raw water coolant outlet & outlet of HX4 (690A)
703	(ΔT) " " " " " on line between 2 engs. (691 &

710 (Actual) outside ambient db
711 (Actual) engine room air temp. db
712 (Actual) outside ambient wb
713 (Actual) engine room air temp. wb

730 (Actual) fuel oil at engines supply FOS
731 (Actual) " " " " return FOR
732 (Actual) " " " boilers supply
733 (Actual) " " " " return

750 (Actual) temp. of exhaust gas on engine entering M-1
751 (Actual) " " " " " " " M-2
752 (Actual) " " " " leaving muffler heat exchangers M-1
753 (Actual) " " " " " " " " M-2

(Actual) HWS to individual buildings
764 Shelley A (east bldg)
765 Camci

(ΔT) at individual buildings HWR's & HWS's (totals)
768 A&B Shelley A
769 A&B Preschool
770 A&B Shelley B
771 A&B School
772 A&B Pool
774 A&B Camci
775 A&B Commercial

(Actual) HW temperature inlet to domestic HW generation
784 Shelley A (east bldg)
785 Camci

(ΔT) Hot water inlet and outlet of domestic heat exchangers
788 A&B Shelley A
789 A&B Preschool
790 A&B Shelley B
791 A&B School
792 A&B Pool
793 A&B Descon-Concordia
794 A&B Camci
795 A&B Commercial

Alarms and Indicators Category (#'s 800 to 899)

800	Engine low oil pressure
801	Engine high water temperature
802	Engine high oil temperature
803	Engine overspeed
804	Engine underspeed
805	Engine excessive vibration
806	Engine high oil coolant temperature
807	Circuit breaker trip
808	Engine excessive start time
809	Generator overload
810	Failure to parallel
811	Reverse power protection
812	Overvoltage
813	Undervoltage
815 to 828	(Same as 800 to 813)
830 to 843	(Same as 800 to 813)
845 to 858	(Same as 800 to 813)
860 to 873	(Same as 800 to 813)

Solid Waste Collection System (PTC) Category (#'s 900 to 950)

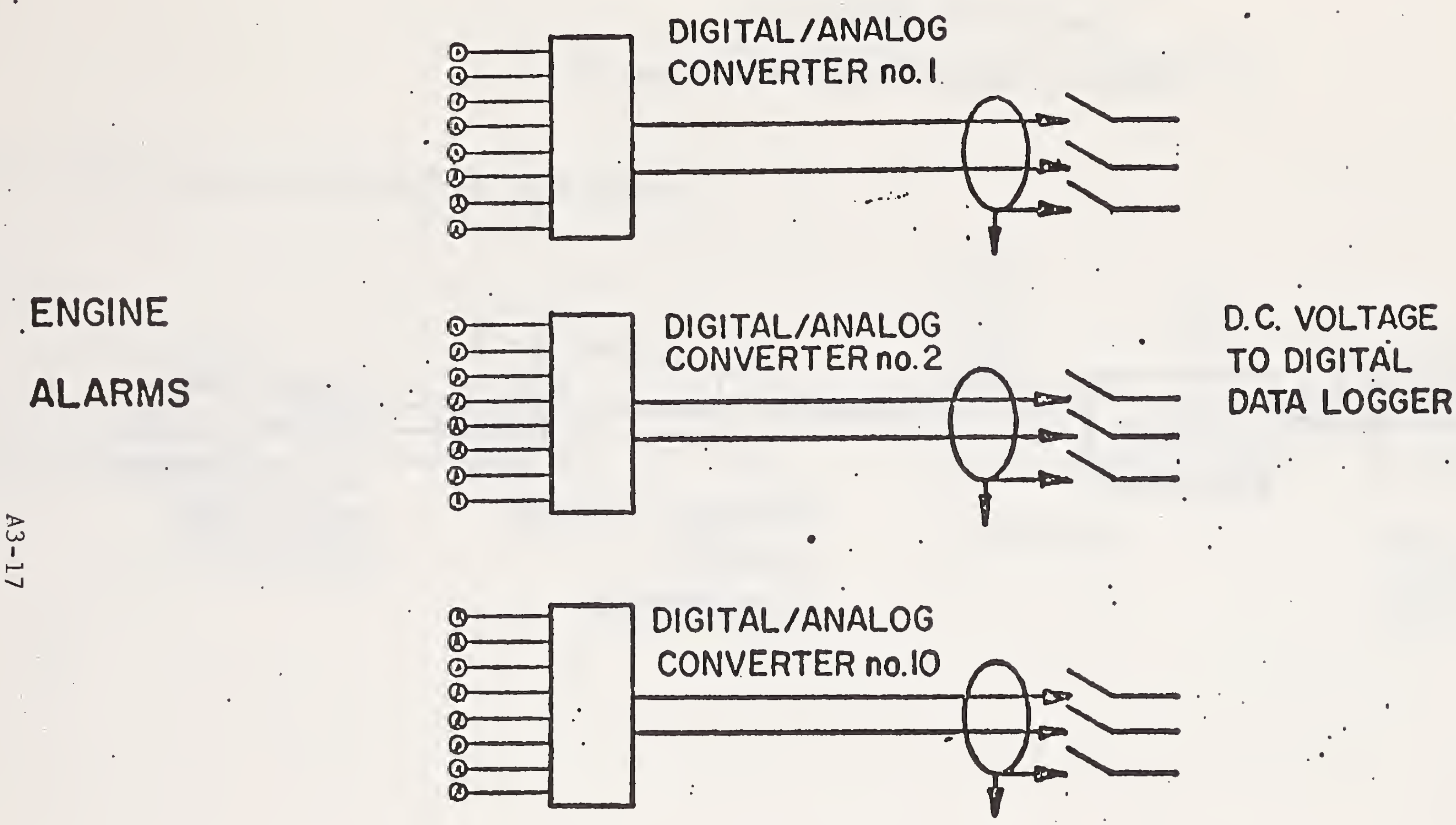
901	Differential pressure
902	Power record
903	Velocity pressure record
904	" " "
905	" " "
906	" " "
907	" " "
908	Static pressure record
909	" " "
910	" " "
911	" " "
912	" " "
913	" " "
914	" " "
915	" " "
916	" " "
917	Static pressure
918	" "
919	" "
920	" "
921	" "
922	" "
923	" "
924	" "
925	" "

926	Signal processor
927	Spare
928	"
929	"
930	"

(29 channels 0-1.25 volts DC, and one channel 0-18 volts DC)

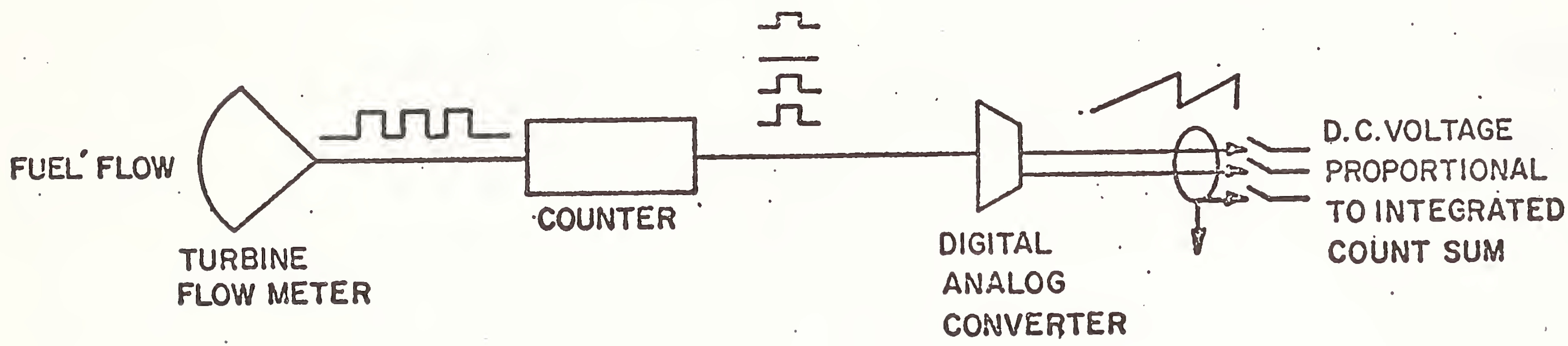
Appendix D. TYPICAL GOVERNMENT PROVIDED TRANSDUCERS

1. Digital Alarm to D.C. Analog Signal



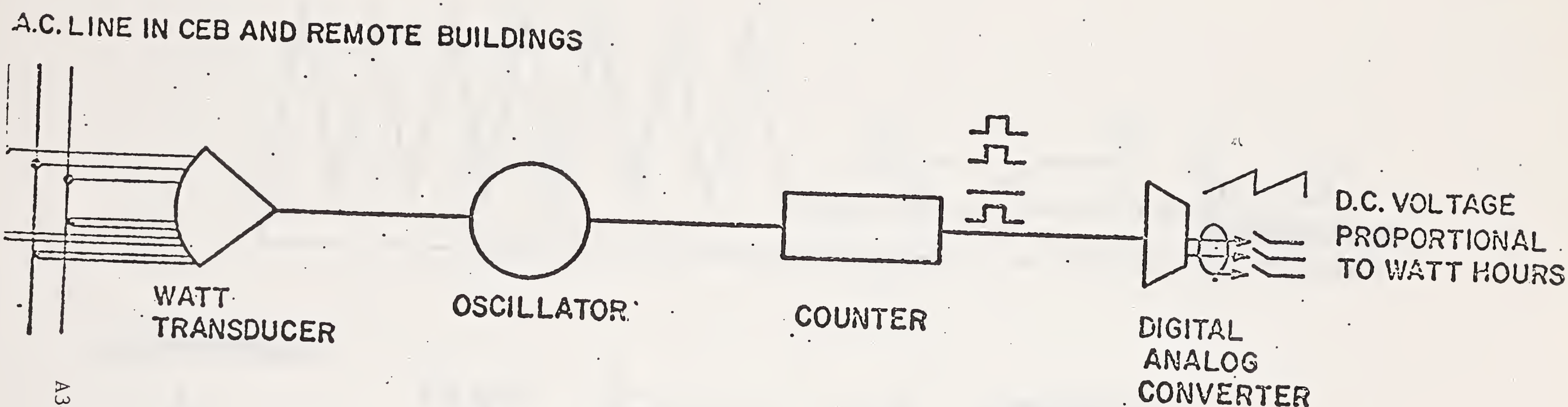
Appendix D (continued)

2. Integrated Output from Turbine Flowmeter

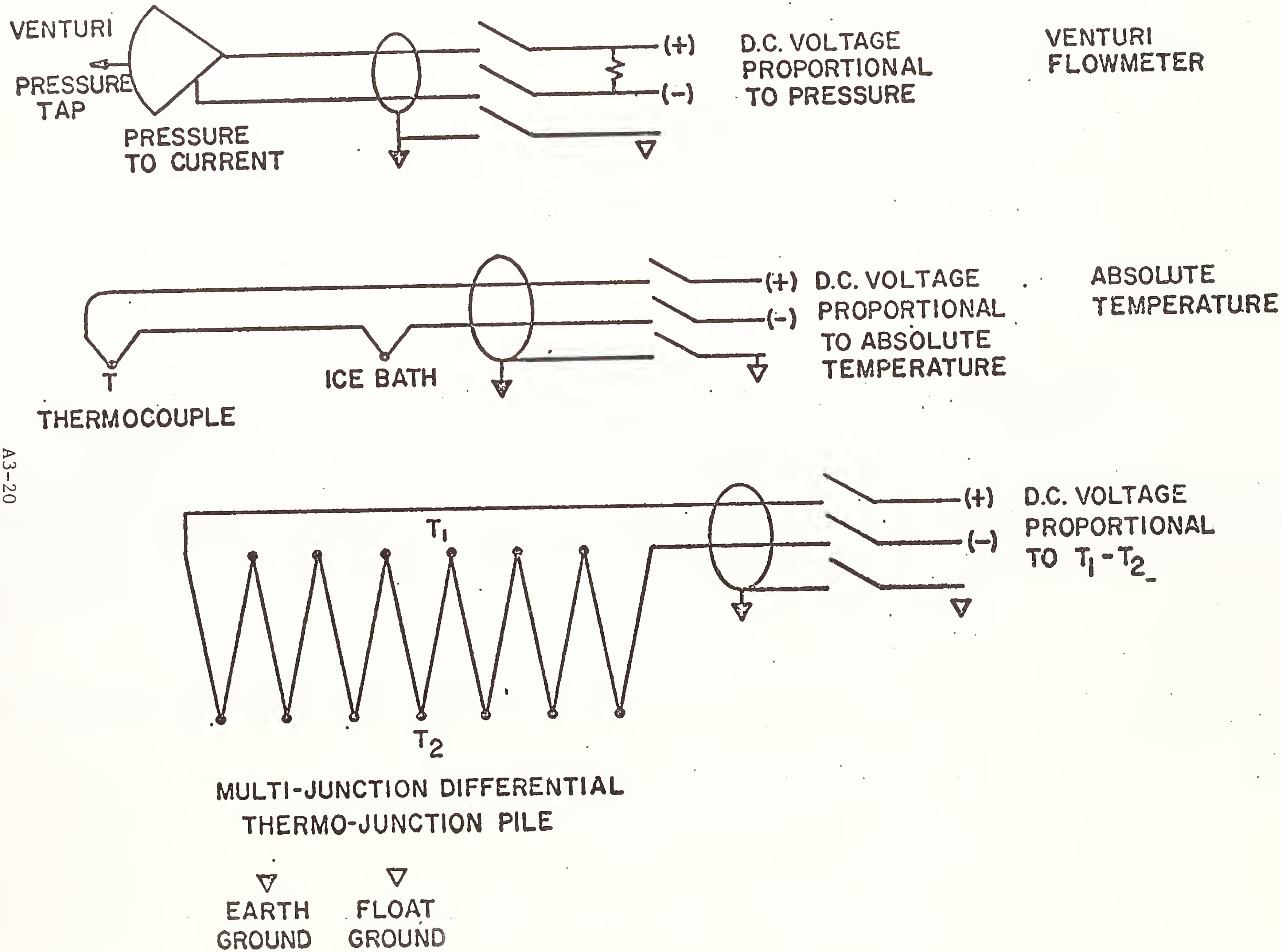


Appendix D (continued)

3. Integrated Watts (Watthours)



4. Venturi Flowmeter, Temperature and Differential Temperatures



APPENDIX 4: Venturi Flow Calibration Report

The Foxboro Company Foxboro, Massachusetts, U S A 02035 • Telephone (617) 543-8750

Flow Calibration Report

FCR72-150R

For

6-Inch Size Vickery-Simms, Inc. Model FFM Short Form Venturi Meter
Serial Number V6-362
Nominal Pipe Internal Diameter: 6.065"
Venturi Throat Diameter: 4.109"
Beta Ratio 0.6774

Tested At

The Foxboro Company Fluid Flow Laboratory
Foxboro, Massachusetts

On

January 8, 1973

Using

Water at Ambient Temperature

Customer: Vickery-Simms, Inc.
Arlington, Texas
Customer Order Number: 0973, Job 7259
Foxboro Sales Order: 72N-46317
Cross Reference: National Bureau of Standards
Gaithersburg, Maryland
Contract Number 2-35917

Report By: Walter E. Wiktorowicz
Walter E. Wiktorowicz
Flow Engineering Department

Approved By: Richard W. Miller
Richard W. Miller
Manager, Flow Engineering Department

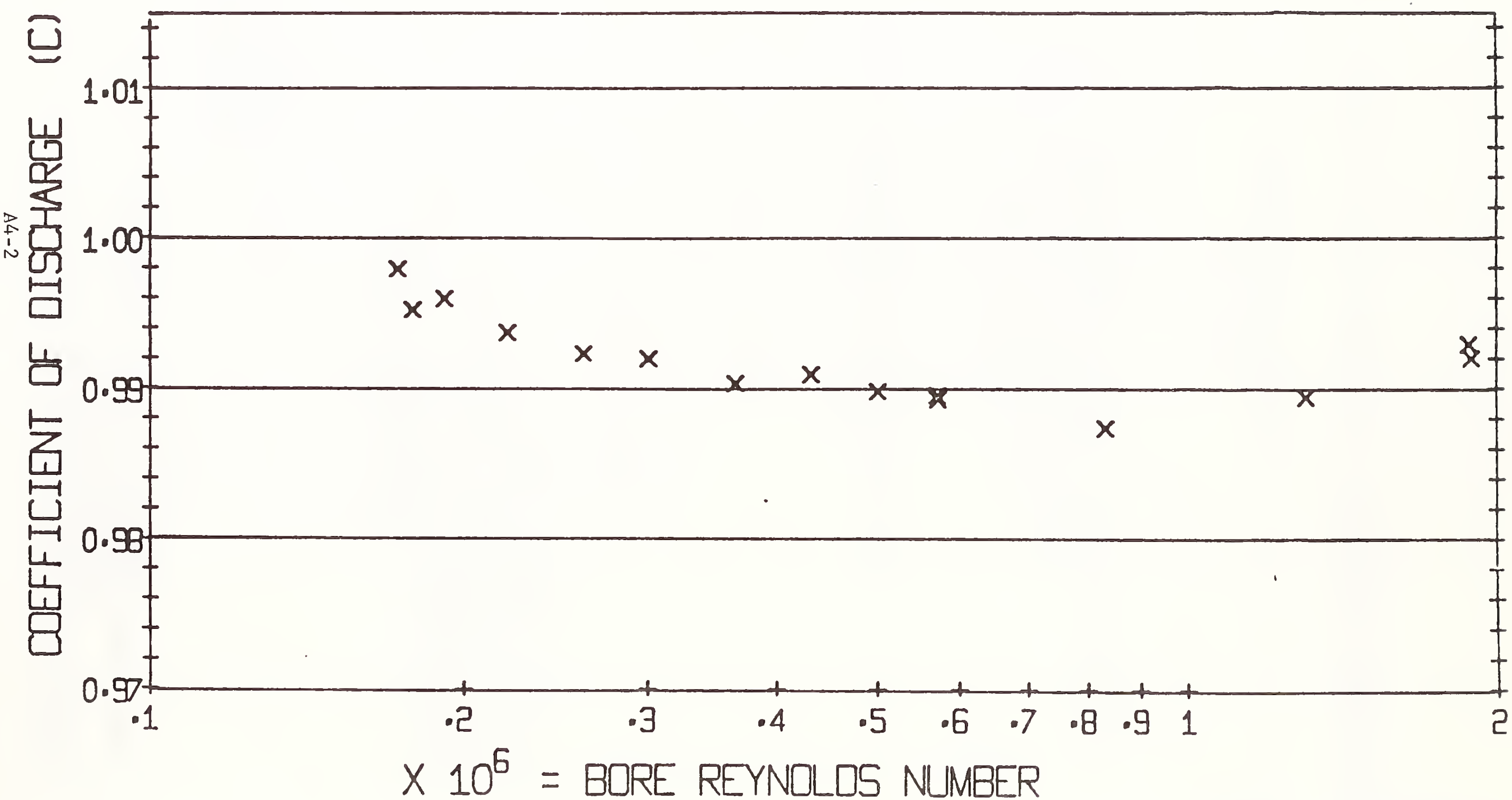
FOXBORO

VENTURI TUBE

COEFFICIENT OF DISCHARGE VS BORE REYNOLDS NUMBER

SALES ORDER 72N-46317
SERIAL NUMBER V6-362

BORE DIA = 4.109
PIPE I.D. = 6.065



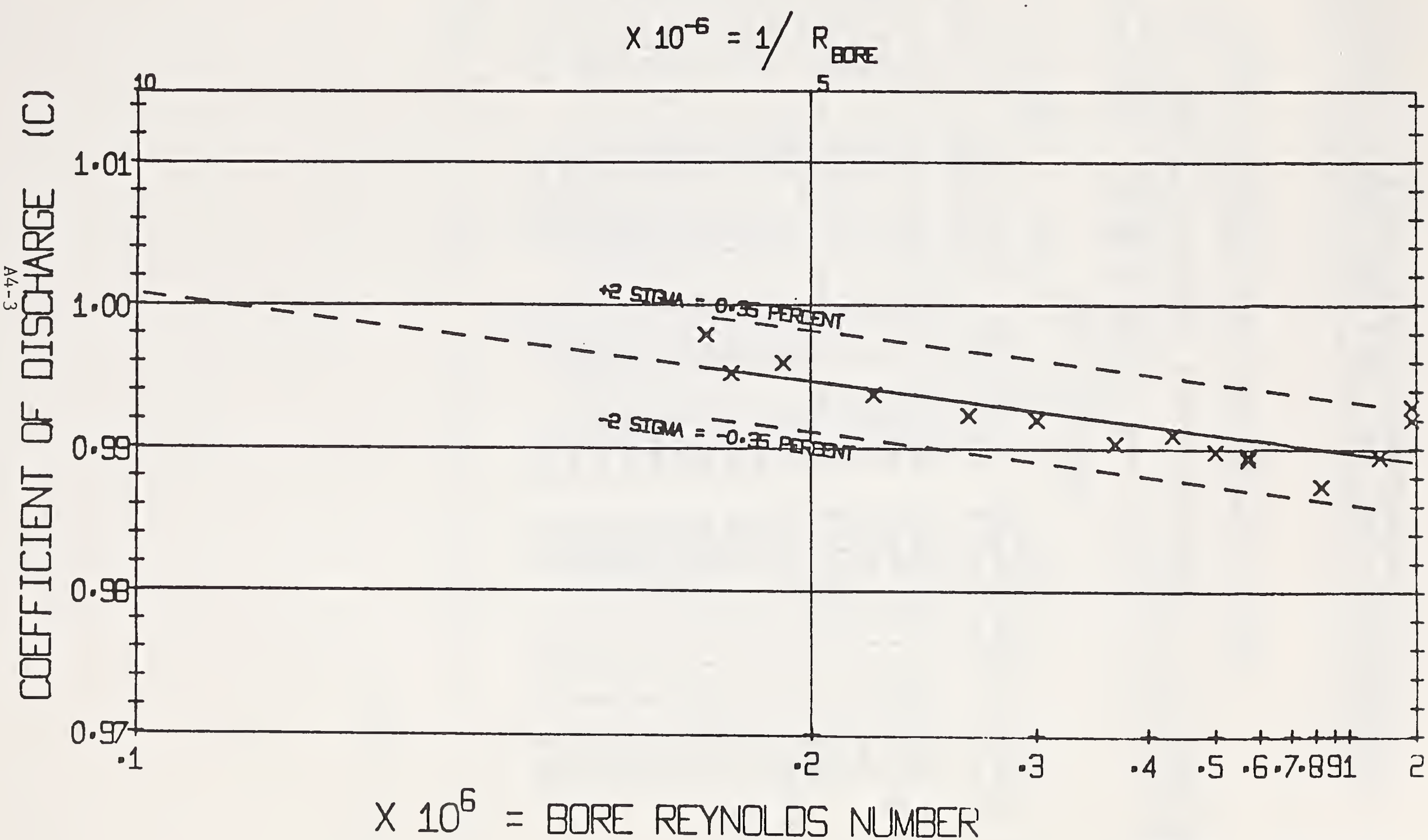
1/8/73 FCR72-150

VENTURI TUBE
FITTED LINE OF REGRESSION
FOR COEFFICIENT OF DISCHARGE VS BORE REYNOLDS NUMBER

SALES ORDER 72N-46317
SERIAL NUMBER V6-362

$C_L = 0.98845 + 1223.74 / R_{BORE}$

BORE DIA = 4.109
PIPE I.D. = 6.065



1/8/73 FCR72-150

FLOW ENGINEERING DEPARTMENT REPORT NO. FCR72-150
VICKERY-SIMMS, INC. FFM SHORT FORM VENTURI METER S/N V6-362
IDENTIFICATION NUMBER 327, REFERENCE DRAWING S-7259-1

METER CALIBRATION BY THE MANOMETER METHOD

BASIC BORE DIA= 4.1090 IN. BASIC PIPE DIA= 6.0650 IN. BETA=0.6774
FLOW FLUID,FL(1)=WATER FL(2)=SPINESSO 34 (FORMULA 1123) OIL
MANO FLUID,MF(1)=MERCURY MF(2)=2.95 SP GR OIL MF(3)=1.75 SP GR OIL

OBSERVED DATA

* RUN NO.	2 TARE WT POUNDS	3 FLOW FLUID	4 FLOW DEG F	5 MANOMETER FLUID	6 DEG F	7 TEST TIME SECONDS	8 GROSS WT POUNDS	9 MANO AVE IN. WET
1	0.0	FL(1)	71.2	MF(1)	74.8	100.860	14541.5	7.606
2	14541.5	FL(1)	71.4	MF(1)	74.9	101.210	37330.0	18.476
3	0.0	FL(1)	71.4	MF(1)	74.9	101.124	33019.5	38.655
4	0.0	FL(1)	71.5	MF(1)	75.1	101.077	32746.0	37.963
5	0.0	FL(1)	71.5	MF(3)	74.8	100.063	2984.1	5.401
6	2984.1	FL(1)	71.5	MF(3)	75.0	101.099	6330.5	6.681
7	0.0	FL(1)	71.5	MF(3)	75.0	101.340	3849.9	8.840
8	3849.9	FL(1)	71.5	MF(3)	75.0	101.130	8402.3	12.446
9	0.0	FL(1)	71.8	MF(3)	75.0	100.903	5215.2	16.419
10	0.0	FL(1)	71.8	MF(3)	75.2	101.414	6360.5	24.261
11	0.0	FL(1)	71.9	MF(3)	75.4	101.057	7496.2	33.900
12	0.0	FL(1)	72.0	MF(3)	75.5	101.191	8700.9	45.658
13	0.0	FL(1)	72.0	MF(3)	75.6	105.892	10395.0	59.578
14	0.0	FL(1)	72.0	MF(3)	75.7	100.851	3087.1	5.724
15	0.0	FL(1)	72.0	MF(3)	75.8	106.444	10443.0	59.481

DATE 1/8/73

FLOW ENGINEERING DEPARTMENT REPORT NO. FCR72-150
VICKERY-SIMMS, INC. FFM SHORT FORM VENTURI METER S/N V6-362
IDENTIFICATION NUMBER 327, REFERENCE DRAWING S-7259-1

METER CALIBRATION BY THE MANOMETER METHOD

BASIC BORE DIA= 4.1090 IN.   BASIC PIPE DIA= 6.0650 IN.   BETA=0.6774

COMPUTED RESULT

* RUN NO.	11 REYNOLDS-NUMBER BORE	12 REYNOLDS-NUMBER PIPE	13 COEFF. K	14 COEFF. C	15 US GPM AT FLOW TEMP	16 PIPE VEL FT/SEC
1	833408.	564628.	1.11134	0.98735	1039.78	11.54
2	1305069.	884176.	1.11364	0.98940	1623.89	18.03
3	1892594.	1282220.	1.11653	0.99196	2354.95	26.15
4	1880326.	1273909.	1.11757	0.99289	2336.56	25.94
5	173088.	117266.	1.12314	0.99784	215.08	2.38
6	192113.	130155.	1.12092	0.99587	238.72	2.65
7	220493.	149383.	1.11841	0.99364	273.99	3.04
8	261268.	177008.	1.11685	0.99225	324.66	3.60
9	301196.	204058.	1.11649	0.99193	372.78	4.13
10	365490.	247617.	1.11463	0.99028	452.35	5.02
11	432853.	293255.	1.11530	0.99087	535.01	5.94
12	502426.	340390.	1.11404	0.98975	620.18	6.88
13	573603.	388612.	1.11344	0.98922	708.04	7.86
14	178863.	121178.	1.12011	0.99515	220.78	2.45
15	573263.	388382.	1.11375	0.98949	707.62	7.85

VEL OF APPROACH FACTOR=1.12557   GEOGRAPHICAL METER COEF. = 0.83131
REYNOLDS NO COEF.= 5751.3

DATE 1/8/73

FLOW ENGINEERING DEPARTMENT REPORT NO.FCR72-150
VICKERY-SIMMS, INC. FFM SHORT FORM VENTURI METER S/N V6-362
IDENTIFICATION NUMBER 327, REFERENCE DRAWING S-7259-1

METER CALIBRATION BY THE MANOMETER METHOD

BASIC BORE DIA= 4.1090 IN. BASIC PIPE DIA= 6.0650 IN. BETA=0.6774

COMPUTED RESULTS AND STATISTICAL ANALYSIS

THE LEAST SQUARE LINE FOR C VERSUS(BORE REYNOLDS NUMBER)**(-1.00)
C (LEAST SQ) = 0.122374E 04*(BORE REYNOLDS NUMBER)**(-1.00)+0.98845
K (LEAST SQ) = 0.933188E 03*(PIPE REYNOLDS NUMBER)**(-1.00)+1.11257

	17	18	19	20	21
RUN NO.	REYNOLDS NO IN BORE,RDB	BORE REYNOLDS NO**(-1.00)	COEFF OF DISCHARGE	C COMPUTED	PC DEV C TO LINE
5	173088.	0.577741E-05	0.99784	0.99552	0.233
14	178863.	0.559088E-05	0.99515	0.99529	-0.014
6	192113.	0.520526E-05	0.99587	0.99482	0.105
7	220493.	0.453528E-05	0.99364	0.99400	-0.036
8	261268.	0.382748E-05	0.99225	0.99313	-0.088
9	301196.	0.332010E-05	0.99193	0.99251	-0.058
10	365490.	0.273605E-05	0.99028	0.99180	-0.153
11	432853.	0.231025E-05	0.99087	0.99128	-0.040
12	502426.	0.199034E-05	0.98975	0.99088	-0.114
15	573263.	0.174440E-05	0.98949	0.99058	-0.110
13	573603.	0.174336E-05	0.98922	0.99058	-0.137
1	833408.	0.119989E-05	0.98735	0.98992	-0.259
2	1305069.	0.766244E-06	0.98940	0.98939	0.001
4	1880326.	0.531823E-06	0.99289	0.98910	0.383
3	1892594.	0.528376E-06	0.99196	0.98910	0.290

ERROR OF ESTIMATE = 0.00176 PERCENT ERROR OF ESTIMATE = 0.178

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Under the sponsorship of the Department of Housing and Urban Development (HUD), the National Bureau of Standards (NBS) gathered engineering data on an operating diesel total energy plant which supplies all electrical power, hot water, and chilled water to a 485 unit apartment/commercial building complex in Jersey City, New Jersey. Engineering data was continously collected from April 1975 to December 1978 by a data acquisition system (DAS) which recorded the outputs from approximately 200 sensors located in the plant and site buildings.

This report describes the design and operation of the instrumentation system and the data acquisition system used to monitor the total energy plant and certain utility services to the site buildings. The report contains a description of the types, characteristics and locations of instruments used to measure physical variables. The capabilities and operational modes of the data acquisition system components are described in detail. The report also contains a brief description of the total energy plant and site, instrument costs, data processing procedures and some of the instrumentation problems encountered.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*
Data acquisition system; Digital tape recorder; Fuel measurement; Instrumentation; Total energy; Transducers; Weather station

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